

THE POTENTIAL GREENHOUSE GAS EMISSIONS OF U.S. FEDERAL FOSSIL FUELS



The Potential Greenhouse Gas Emissions of U.S. Federal Fossil Fuels

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I. Executive Summary

This report was undertaken to facilitate a better understanding of the consequences of future federal fossil fuel leasing and extraction in the context of domestic and global efforts to avoid dangerous climate change. We estimate the potential greenhouse gas (GHG) emissions from developing the remaining fossil fuels in the United States (U.S.), including the emissions from developing publicly owned, unleased federal fossil fuels that constitute 450 billion tons of CO₂e.

We report the volume of these fossil fuels, including that of leased and unleased federal fossil fuels located beneath federal and non-federal lands and the outer continental shelf. These resource appraisals are used to estimate the life-cycle GHG emissions associated with developing crude oil, coal, natural gas, tar sands, and oil shale—including emissions from extraction, processing, transportation, and combustion or other end uses. We express potential emissions in gigatons (“Gt”) (one gigaton equals one billion tons) of carbon dioxide equivalent (CO₂e), and discuss them below in the context of global emissions limits and nation-specific emissions quotas.

Major findings are that:

- The potential GHG emissions of federal fossil fuels (leased and unleased) are 349 to 492 Gt CO₂e, representing 46% to 50% of potential emissions from all remaining U.S. fossil fuels. Federal fossil fuels that have not yet been leased for development contain up to 450 Gt CO₂e.
- Unleased federal fossil fuels comprise 91% of the potential GHG emissions of all federal fossil fuels. The potential GHG emissions of unleased federal fossil fuel resources range from 319-450 Gt CO₂e. Leased federal fossil fuels represent from 30-43 Gt CO₂e.
- The potential emissions from unleased federal fossil fuels are incompatible with any U.S. share of global carbon limits that would keep emissions below scientifically advised levels.

Potential GHG Emissions from U.S. Federal Fossil Fuels

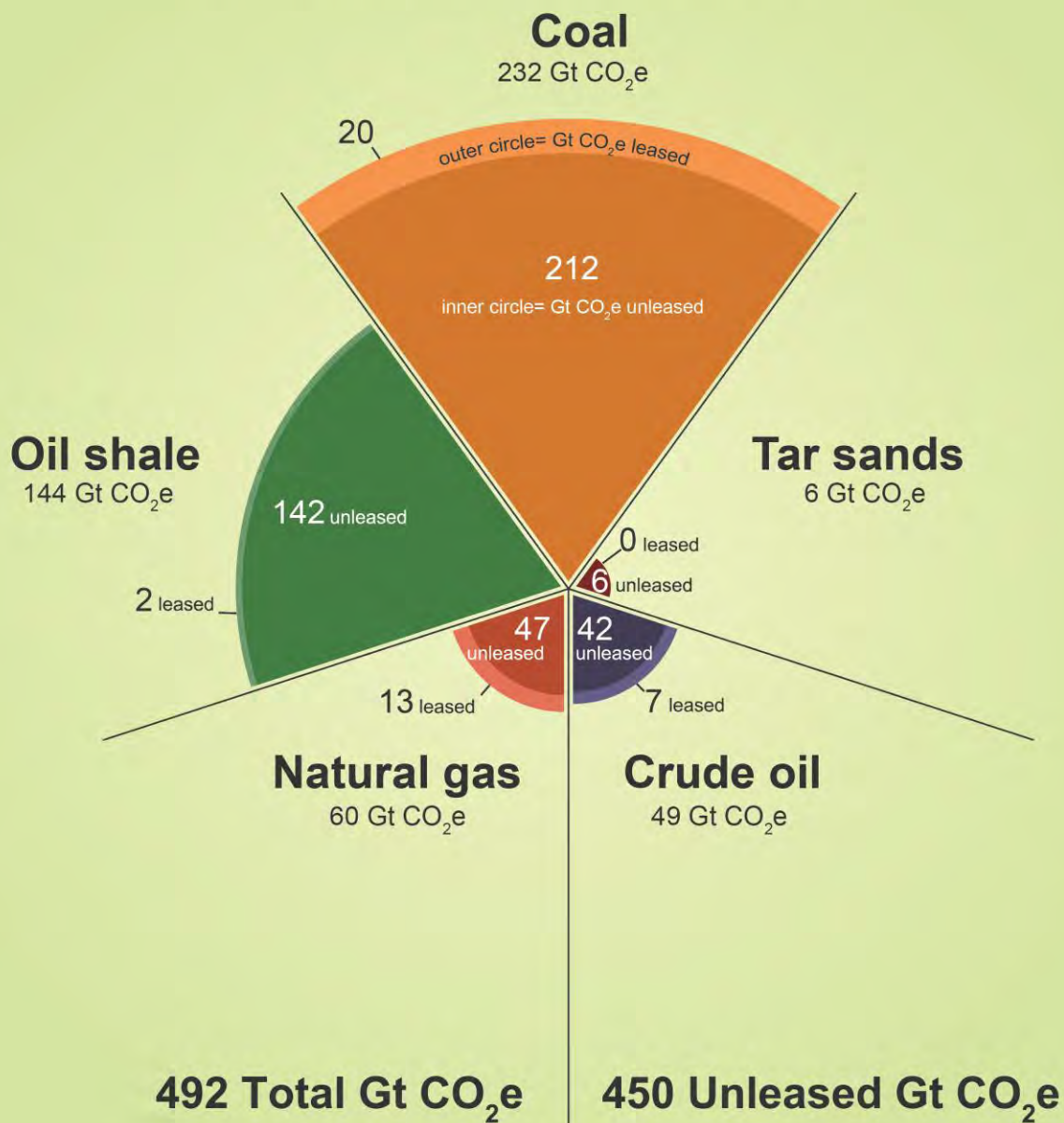


Figure 1. Potential emissions of leased and unleased federal fossil fuels.

Our results indicate that a cessation of new federal fossil fuel leasing could keep up to 450 Gt CO₂e from the global pool of potential future GHG emissions. (Figure 1.) This is equivalent to 13 times global carbon emissions in 2014 or annual emissions from

118,000 coal-fired power plants. This has a significant potential for GHG emissions savings that is best understood in the context of global limits and national emissions quotas.

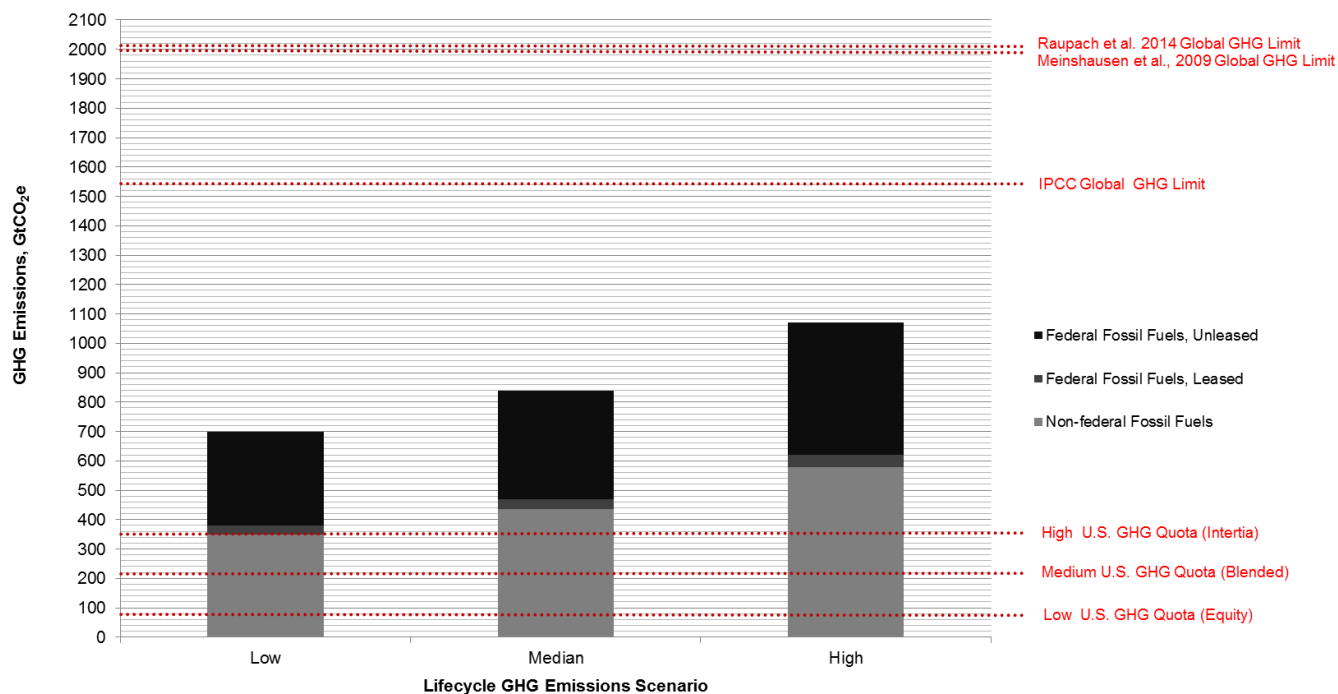
Carbon emission quotas are the maximum amount of greenhouse gases humanity can emit while still preserving a given chance of limiting average global temperature rise to a level that will not be catastrophic. The Intergovernmental Panel on Climate Change has recommended efforts to ensure that temperature increases remain below 2°C by century's end, a level at which dramatic adverse climate impacts are still expected to occur. Nation-specific emissions quotas are the amount of greenhouse gas emissions that an individual country can emitⁱ.

Studies that have apportioned global emissions quotas among the world's countries indicate that the U.S. share of the global emissions is limited, with varying estimates depending on the equity principles used. For example, Raupach et al. (2014) estimated three U.S. GHG emissions quota scenarios of 85Gt CO₂e, 220 Gt CO₂e, and 356 Gt CO₂e necessary to maintain only a 50 percent likelihood of avoiding 2°C (3.6°F) warming by century's end, depending on the equity assumptions used within a total global emissions limit. These represent a range of approximate equity assumptions for apportioning emissions quotas.ⁱⁱ Under any of those quotas, emissions from new federal fossil fuel leasing are precluded after factoring in the emissions of developing non-federal and already leased fossil fuels. (Figure 2.)

ⁱ In this report we use the terms "share of limit" and "quota" interchangeably and define them in the context of scientifically advised emission limitations exclusive of sequestration. In some cases, studies and reports also use the term "budget". Much of the literature, coverage, and usage of these issues utilize the terms in this way; however, in some cases carbon "budgets" are defined more broadly to encompass sources, fluxes and sinks; while "quotas" are defined more narrowly to encompass only limits on future emissions necessary to meet a certain average global temperature target. We feel this usage is appropriate here since "carbon budgets" generally refer to the total cumulative mass of carbon emissions allowable over time, while this report describes the total cumulative mass of carbon under federal and non-federal lands which may or may not be emitted into the atmosphere over time.

ⁱⁱ We use Raupach et al. (2014) U.S. emissions quotas for illustration purposes only; this report and its authors do not endorse equity assumptions made therein. We use the ratio of 1.39 CO₂e/CO₂ reported in Meinshausen et al. (2009) to convert the values reported in Raupach et al. (2014) from CO₂ to CO₂e. We also exclude Raupach et al.'s "future committed emissions" from their published -30, 67 and 165 GtCO₂ U.S. quotas to isolate the quotas from assumptions about "future committed emissions." Notably, under Raupach et al.'s "equity" scenario, "future committed emissions" already exceed the remaining U.S. quota; Raupach et al. thus report a remaining "equity" scenario quota of -30 Gt CO₂.

Potential Lifecycle GHG Emissions of Federal and Non-federal Fossil Fuels, and Global GHG Limits and U.S. GHG Quotas to Maintain 50% Likelihood of Keeping Warming Below 2°C (3.6°F) *



* GHG limits and quotas published in CO₂ are displayed in CO₂e using the ratio of 1.39 CO₂e/CO₂ reported in Meinshausen et al. (2009). U.S. GHG quotas from Raupach et al. 2014. Limits and quotas are lower for maintaining higher likelihood of limiting warming to below 2°C and/or keeping warming below a lower temperature, like 1.5°C.

Figure 2. Global carbon limits, U.S. emissions quotas and potential emissions from federal and non-federal fossil fuels.

II. Introduction

The Intergovernmental Panel on Climate Change (IPCC) recently warned that humanity must adhere to a strict “carbon limit” in order to preserve a likely chance of holding average global warming to less than 2°C (3.6°F) by the end of the century—a level of warming that still will cause extreme disruption to both human communities and natural ecosystems.¹ According to the IPCC, all future global emissions must be limited to about 1,000 gigatons (“Gt,” one gigaton equals one billion tons) of carbon dioxide (CO₂) to have a likely (>66%) chance of staying below 2°C.² The International Energy Agency has projected that the entire remaining 1,000 Gt CO₂ (1,390 Gt CO₂eⁱⁱⁱ) carbon budget will be consumed by 2040 on the current emissions course.³

Carbon quotas are the maximum amount of greenhouse gases humanity can emit while still preserving a given chance of limiting average global temperature rise to a level that will not be catastrophic. The Intergovernmental Panel on Climate Change has used a carbon limit to keep temperature increases below 2°C by century’s end, a level at which dramatic adverse climate impacts are still expected to occur. Nation-specific emissions

quotas are the amount of greenhouse gas emissions that an individual country can emit.^{iv}

Studies that have apportioned global emissions quotas among the world's countries indicate that the U.S. share of the global emissions is limited, with varying estimates depending on the equity principles used. For example, Raupach et al. (2014) estimated three U.S. GHG emissions quota scenarios of 85 Gt CO₂e, 220 Gt CO₂e, and 356 Gt CO₂e necessary to maintain only a 50 percent likelihood of avoiding 2°C (3.6°F) warming by century's end, depending on the equity assumptions used within a total global emissions limit. These represent a range of approximate equity assumptions for apportioning emissions quotas.^v Under any of those quotas, emissions from new federal fossil fuel leasing are precluded given the potential emissions from already-leased federal fossil fuels and those of non-federal fossil fuels.

Raupach et al.'s three scenarios are based on:

- High (inertia): Favors “grandfathering” of emissions, favoring a distribution of quota emissions to nations or regions with higher historical emissions.
- Medium (blended): Blends “inertia” and “equity” emissions.
- Low (equity): Favors a distribution of quota emissions based on population distribution, or emissions per capita, in regions or nations.

In 2013, the U.S. emitted 6.67 Gt CO₂e,⁴ the majority (85%) coming from the burning of fossil fuels,⁵ and accounting for 15% of global emissions.⁶ A 2015 analysis by an international team of climate experts⁷ suggests that for a likely probability of limiting warming to 2°C, the U.S. must reduce its GHG emissions in 2025 by 68 to 106% below 1990 levels, with the range of reductions depending on the sharing principles used.⁸ Accordingly, U.S. GHG annual emissions in 2025 would have to range between 2 Gt CO₂e (i.e., 68% below 1990) and negative emissions of -0.4 Gt CO₂e (i.e., 106% below 1990), significantly below current emissions of ~6.7 Gt CO₂e. Where negative emissions are required, the remaining carbon budget has been exhausted.

Under the current U.S. “all of the above” energy policy, federal agencies lease lands to private companies to extract and sell federal fossil fuel resources, including submerged offshore lands of the outer continental shelf. Leases initially last ten years, or twenty

^{iv} Emissions quotas are one among many mechanisms for determining equity and fairness in international climate negotiations. Equity principles generally include assumptions about different countries' historical responsibility for climate emissions, their ability to mitigate emissions, as well as measures of developed country support for emissions mitigation and adaptation in developing countries. While we are only using emissions quotas to illustrate the size of U.S. fossil fuel resources, we recognize that emissions quotas cannot be discussed independently from climate finance commitments.

^v We use Raupach et al. (2014) U.S. emissions quotas for illustration purposes only; this report and its authors do not endorse equity assumptions made therein. We use the ratio of 1.39 CO₂e/CO₂ reported in Meinshausen et al. (2009) to convert the values reported in Raupach et al. (2014) from CO₂ to CO₂e. We also exclude Raupach et al.'s “future committed emissions” from their published -30, 67 and 165 GtCO₂ U.S. quotas to isolate the quotas from assumptions about “future committed emissions.” Notably, under Raupach et al.'s “equity” scenario, “future committed emissions” already exceed the remaining U.S. quota; Raupach et al. thus report a remaining “equity” scenario quota of -30 Gt CO₂.

years in the case of coal, and may continue indefinitely once successful mineral extraction begins. Though these leases collectively span many tens of millions of acres, federal agencies do not currently track or report the nation-wide cumulative GHG emissions that result from federal leasing of fossil fuel reserves. There have been studies that account for past emissions from federal fossil fuel leasing. For example, a 2014 Stratus Consulting report completed for The Wilderness Society, titled *Greenhouse Gas Emissions from Fossil Energy Extracted from Federal Lands and Waters: An Update*, estimated that, in calendar year 2012, emissions from federal fossil fuel production were 1.344 Gt CO₂e, or 21% of all U.S. GHG emissions that year.⁹ A 2015 analysis completed by the Climate Accountability Institute for the Center for Biological Diversity and Friends of the Earth estimated that federal fossil fuel production accounted for 1.278 Gt CO₂e of emissions in 2012, and during the past decade contributed approximately 25% of all U.S. GHG emissions associated with fossil fuel consumption, which represents around 3-4% of global fossil fuel emissions during that time.¹⁰ Yet, there has been no assessment of the potential GHG savings from sequestering remaining unleased federal fossil fuels.

This report models the total amounts and potential GHG emissions associated with the remaining federal and non-federal fossil fuels in the U.S. We compiled federal and industry inventories of total fossil fuel resources and, using standard life-cycle assessment guidelines, we calculated life-cycle GHG emissions associated with all phases of developing federal and non-federal coal, crude oil, natural gas, tar sands, and oil shale resources. We evaluated low, median, and high emission scenarios for each of the fossil fuels studied to account for some of the uncertainties associated with producing some fossil fuels.

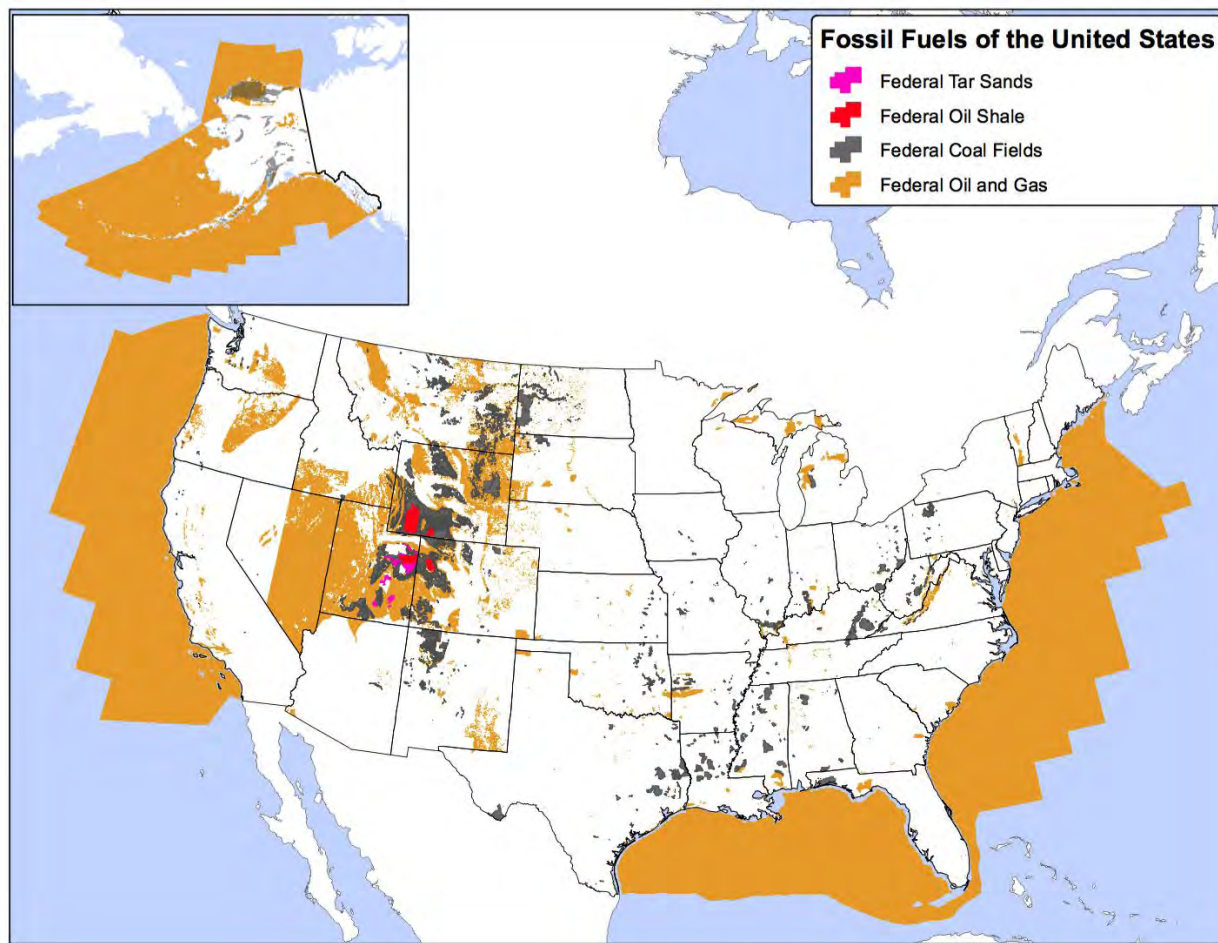


Figure 3. Map of U.S. Federal Fossil Fuels.

Our analysis focuses on the potential GHG emissions from the remaining unleased federal fossil fuel resources in the U.S. Keeping these fossil fuels in the ground would contribute significantly to global efforts to prevent combustion emissions from remaining fossil fuel resources. For the purposes of this report, unleased federal fossil fuels are those federal fossil fuel resources that are not currently leased to private companies. They include unleased recoverable federal coal reserves, federal oil shale, federal crude oil, federal natural gas, and federal tar sands. Unleased federal fossil fuels include resources that are available for leasing under current federal policy and that could become available for leasing under future federal policy.¹¹

Key terms

All U.S. fossil fuels include all federal and non-federal recoverable coal reserves, oil shale, crude oil, natural gas and tar sands (onshore and offshore).

Federal fossil fuels are federally controlled, publicly owned fossil fuel resources. Federal fossil fuels are located beneath lands under federal and other ownerships, where the federal government owns subsurface mineral rights. They are also located “offshore,” beneath submerged public lands of the outer continental shelf. Federal fossil fuels include recoverable federal coal reserves, federal oil shale, federal crude oil, federal natural gas and unleased federal tar sands.

Leased federal fossil fuels are federal fossil fuel resources, including proved reserves and resources under non-producing leased land, as classified by the Bureau of Ocean Energy Management (BOEM) and Bureau of Land Management (BLM), which are currently leased to private companies. These include leased federal recoverable coal reserves, leased federal oil shale, leased federal crude oil, leased federal natural gas and leased federal tar sands.

Non-federal fossil fuels are fossil fuel resources calculated by subtracting federal fossil fuel amounts from total technically recoverable oil resources, total technically recoverable natural gas resources, and total recoverable coal reserves in the United States as provided by EIA 2012a.

Unleased federal fossil fuels are federal fossil fuel resources that are not leased to private companies. These include unleased recoverable federal coal reserves, unleased federal oil shale, unleased federal crude oil, unleased federal natural gas, and unleased federal tar sands.

Recoverable coal reserves are the portion of the Demonstrated Reserve Base that the Energy Information Agency estimates may be available or accessible for mining.

Federal recoverable coal reserves are the federally controlled portion of recoverable coal reserves.

Crude oil is onshore and offshore technically recoverable federal and non-federal crude oil resources. **Federal crude oil** is federally controlled crude oil.

Natural gas is onshore and offshore technically recoverable federal and non-federal natural gas resources. **Federal natural gas** is federally controlled natural gas.

Federal oil shale is federally controlled oil shale that is geologically prospective according to deposit grade and thickness criteria in the Bureau of Land Management’s 2012 Final Oil Shale and Tar Sands Programmatic Environmental Impact Statement (PEIS) and Record of Decision (ROD). Geologically prospective oil shale resources in

Colorado and Utah are deposits that yield 25 gallons of oil per ton of rock (gal/ton) or more and are 25 feet thick or greater. In Wyoming geologically prospective resources are deposits that yield 15 gal/ton or more and are 15 feet thick or greater.

Tar sands are estimated in-place tar sands resources. **Federal tar sands** are federally controlled tar sands.

Proved or proven reserves are estimated volumes of hydrocarbon resources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. Reserve estimates change from year to year as new discoveries are made, existing fields are more thoroughly appraised, existing reserves are produced, and prices and technologies change. Because establishing proved reserves requires drilling, which first requires leasing, proved federal fossil fuel reserves are necessarily leased, and unleased federal fossil fuels necessarily are not proved.

Technically recoverable refers to oil and gas resources that are unleased but producible using current technology without reference to their economic viability.

In-place resource is the entire fossil fuel resource in a geologic formation regardless of its recoverability or economic viability.

II. Research Methodology

Greenhouse gas (GHG) emissions associated with developing fossil fuel resources were estimated by (a) quantifying the volume and energy value of federal and non-federal fossil fuels, (b) determining the end uses and proportions of different end-use products made from fossil fuels, and (c) estimating the total GHG emissions from developing these resources and processing them into end-use products, by multiplying the total volume energy value of fossil fuel products by their life-cycle emissions factors.



Figure 4. Research methodology

A) Quantifying Fossil Fuel Resources Volumes and Energy Values

Federal and non-federal fossil fuel quantities were obtained from federal estimates by the Bureau of Land Management (BLM), Energy Information Agency (EIA), U.S. Geological Survey (USGS), Office of Natural Resource Revenue (ONRR), the Department of Interior (DOI), and Congressional Research Service (CRS). Federal agencies similarly report the technically recoverable resources for crude oil and natural gas based on a consistent definition. For coal, agencies estimate recoverable coal by assessing the accessibility and recovery rates for the demonstrated coal base. For oil shale and tar sands the quantity is based on the resource available and in-place resources, which do not attempt to characterize the resource based on the likelihood of development. Unleased volumes of federal fossil fuels were calculated by subtracting leased volumes from the sum of technically recoverable quantities.

Quantities of federal and non-federal crude oil, natural gas, coal, oil shale and tar sands were summed and converted into values that represent each fossil fuel's energy content, called its primary energy value. This was done by multiplying the fossil fuel volumes by a heating value factor that represents the resource's energy content. Lower Heating Values were used for all fuels except coal, where the Higher Heating Value was taken as per convention for solid fuels in the U.S. Heating values for each resource were taken from Oak Ridge National Laboratory (ORNL), and can be found in the *Fossil Fuel Volumes to Primary Energy Conversions* section in Appendix I.

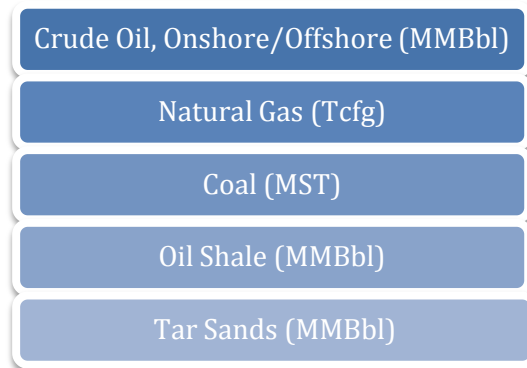


Figure 5. Fossil fuels analyzed

Figure 3 above shows the five fossil fuel types analyzed as they are broadly defined by federal agencies: Oil (onshore and offshore), gas (onshore and offshore) coal, oil shale and tar sands. The hydrocarbons included within federal oil and gas definitions are reported in Table 1 below.

Fossil fuel type	Crude oil	Condensate	Natural gas liquids	Dry natural gas	Gas, wet after lease separation	Non-associated gas, wet after separation	Natural gas associated-dissolved, wet after lease separation	Coalbed methane
Onshore oil	x	X	x					
Offshore oil	x	X	x					
Onshore gas				x	x	x	x	x
Offshore gas				x	x	x	x	x

Table 1. Hydrocarbons in the categories of crude oil and natural gas

B) Determining the End-Use Products Made from Fossil Fuels

Each fossil fuel resource was converted to a value that represents its energy content and divided into amounts used as inputs for different end-use products. We allocated the proportions of each resource into end-use products as follows:

- The energy in crude oil resources was proportionally divided into: finished motor gasoline, distillate fuel oil, kerosene, liquefied petroleum gases (LPG), petroleum coke, still gas and residual fuel oil.
- The energy in natural gas resources was split into residential, commercial, industrial, electric power and transportation end-use sectors.
- The energy in coal reserves was divided to electric power, coke and other industrial uses.
- Energy in tar sands and oil shale was assumed to be processed into end-use products analogous to crude oil.

These proportions make it possible to apply end-use product specific life-cycle emissions factors. For each product we determined the amount that could be yielded from the initial energy after processing, using a “primary energy factor” derived from

figures and conversion factors from sources in the literature, such as those developed at the National Renewable Energy Laboratory (NREL).

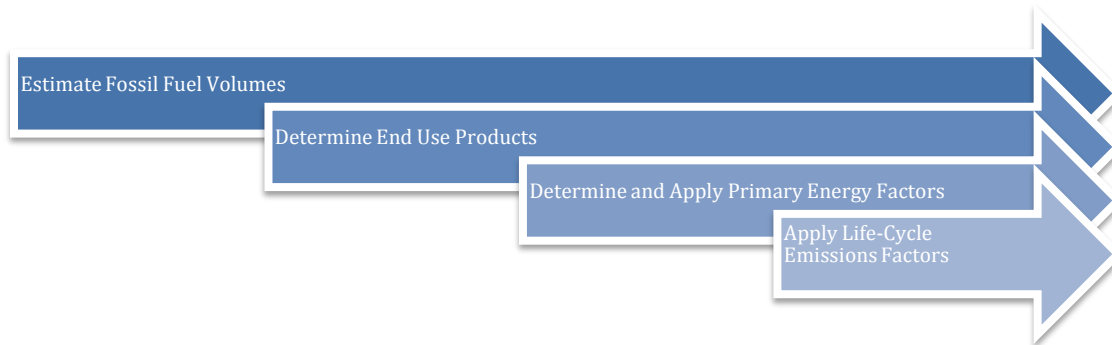


Figure 6. Steps to determine fossil fuel amounts and apply specific energy and emissions factors

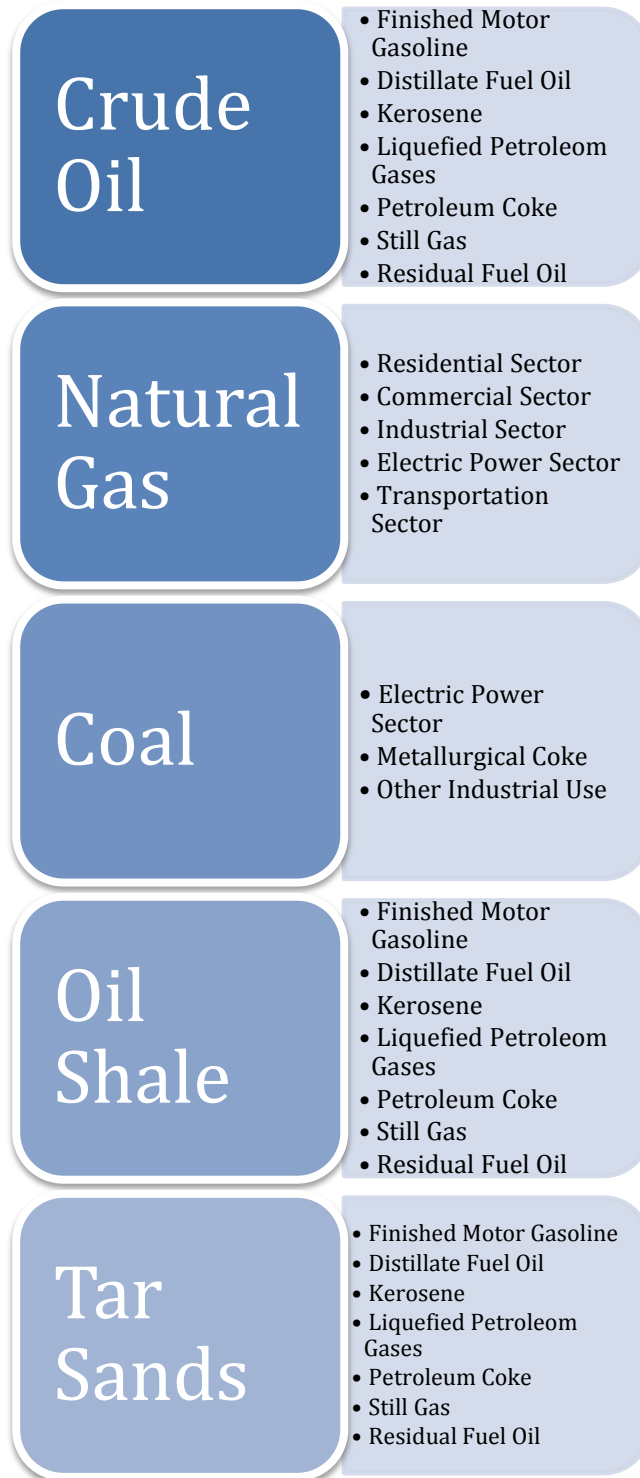


Figure 7. Fossil fuel resources and end-use products and sectors

C) Multiplying the Quantity of Fossil Fuel Energy by GHG Emissions Factors

The total energy value of each fossil fuel product end use was multiplied by product-specific life-cycle emissions factors to estimate the total GHG emissions. Life-cycle GHG emissions factors represent the amount of GHGs released when burning one unit 15

of energy. In peer-reviewed life-cycle assessments of fossil fuels, there are uncertainties associated with the GHG emissions of some fuels. For example, the life-cycle emissions associated with land use change resulting from coal extraction can be a source of uncertainty given differing amounts of methane leakage. To account for these uncertainties, the analysis used three scenarios for each fossil fuel corresponding to high, median, low GHG emissions factors reported in the scientific literature. The low GHG emissions factor scenario was chosen as the base case, and the high emissions factor scenario is the worst case scenario (most inefficient use of fossil fuels).

Each scenario represents different magnitudes (high, median and low) of global warming pollution associated with different fossil fuels. The high emissions scenario represents the worst-case greenhouse gas pollution scenario. Where available we used emissions factors from research by the U.S. national energy laboratories including Argonne National Laboratories' GREET tool and several meta-analyses from NREL that produced harmonized emissions-factors based on extensive prior research. Although emissions factors can vary following changes in any of the parameters in the underlying study, Table 2 in Appendix II highlights key parameters that significantly affect the magnitude of the emission factor and consequently influence whether it is characterized as low, median or high.

Where necessary, the following end-use product specific adjustments were made to improve the accuracy of life-cycle emissions factors:

- A carbon storage factor was determined for the following end-use products: metallurgical coke from coal, distillate fuel, liquefied petroleum gases (LPGs), petroleum coke from crude oil, and still gas.¹² This is to account for a proportion of carbon in the fossil fuel resource that is stored in the end product and not combusted or otherwise emitted. For example, some of the carbon in petroleum coke remains in products such as urea and silicon carbide, and the carbon storage factor reflects this.
- A shale-play weighting factor was applied to calculate emissions from natural gas to account for some studies that suggest that there may be higher amounts of methane released with natural gas extracted from shale versus conventional resources.¹³
- These calculations were summed to present results in 100-year Global Warming Potentials, represented as gigatons CO₂ equivalent (Gt CO₂e).

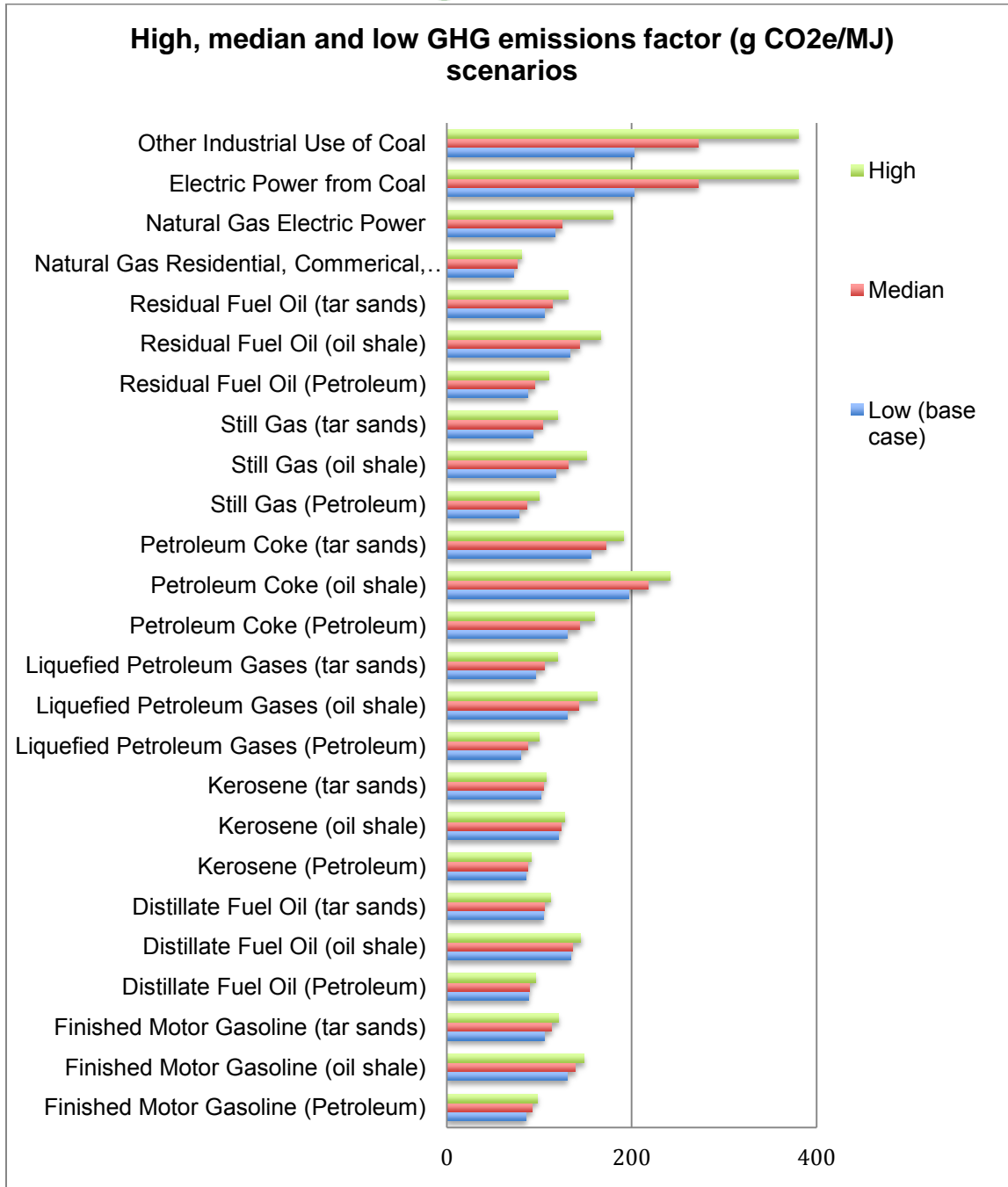


Figure 8. High, median and low (base case) GHG emissions factor scenarios.

Appendix I provides detailed methodologies for estimating fossil fuel volumes, converting fossil fuel volumes to primary energy, and calculating resource and end-use product-specific life-cycle emission factors. The full list of sources used to estimate fossil fuel amounts, primary energy factors, proportions of end-use products and sectors, carbon storage factors, and product specific life-cycle emissions factors are available in Appendix II.

III. Results

Our results indicate that:

1. The potential GHG emissions federal fossil fuels, leased and unleased, are 348.96 to 492.22 Gt CO₂e, representing 46% to 50% of potential emissions from all remaining U.S. fossil fuels; The potential GHG emissions of federal and non-federal fossil fuels are 697-1,070 Gt CO₂e. Unleased federal fossil fuels comprise 91% of the potential GHG emissions of all federal fossil fuels. The potential GHG emissions of unleased federal fossil fuel resources range from 319.00 to 449.53 Gt CO₂e. Leased federal fossil fuels represent from 29.96 to 42.69 Gt CO₂e;
2. Unleased federal recoverable coal accounts for 36% to 43% of the potential GHG emissions of all remaining federal fossil fuels, from 115.32 to 212.26 Gt CO₂e. Leased federal recoverable coal represents from 10.68 to 19.66 Gt CO₂e of potential emissions.
3. Unleased federal oil shale accounts for 29% to 35% of potential GHG emissions of all remaining federal fossil fuels, ranging from 123.17 to 142.07 Gt CO₂e. Leased federal oil shale accounts for 0.3% to 0.6% of potential GHG emissions of all remaining federal fossil fuels, representing 2 Gt CO₂e;
4. Unleased federal natural gas accounts for 10% to 11% of potential GHG emissions of all remaining federal fossil fuels, ranging from 37.86 to 47.26 Gt CO₂e, of which 36% are onshore and 64% are offshore. Leased federal gas represents 10.39 to 12.88 Gt CO₂e, 47% of which are onshore and 53% are offshore.
5. Unleased federal crude oil accounts for 9% to 12% of potential GHG emissions of all remaining federal fossil fuels, ranging from 37.03 to 42.19 Gt CO₂e, of which 28% are onshore and 72% are offshore. Potential emissions from leased federal crude oil represents from 6.95 to 7.92 Gt CO₂e, of which 33% are onshore and 67% are offshore.
6. Unleased federal tar sands accounts for 1% to 2% of potential GHG emissions of all remaining federal fossil fuels, ranging from 5.62 to 5.75 Gt CO₂e.

Federal versus non-federal fossil fuels

The potential GHG emissions from federal and non-federal fossil fuels were compared to contextualize the proportion that is federally owned. The results indicate that 34% of all remaining fossil fuels, based on the energy content of those fuels, are federally owned; these represent 348.96 to 492.22 Gt CO₂e of potential GHG emissions.

Table 2. GHG emissions, in GtCO₂e, from federal and non-federal fossil fuels

	Low	Median	High
Federal Leased	29.96	34.65	42.69
Federal Unleased	319.00	369.98	449.53
Non-federal	348.49	435.14	577.78
Total	697.45	839.77	1,070.00

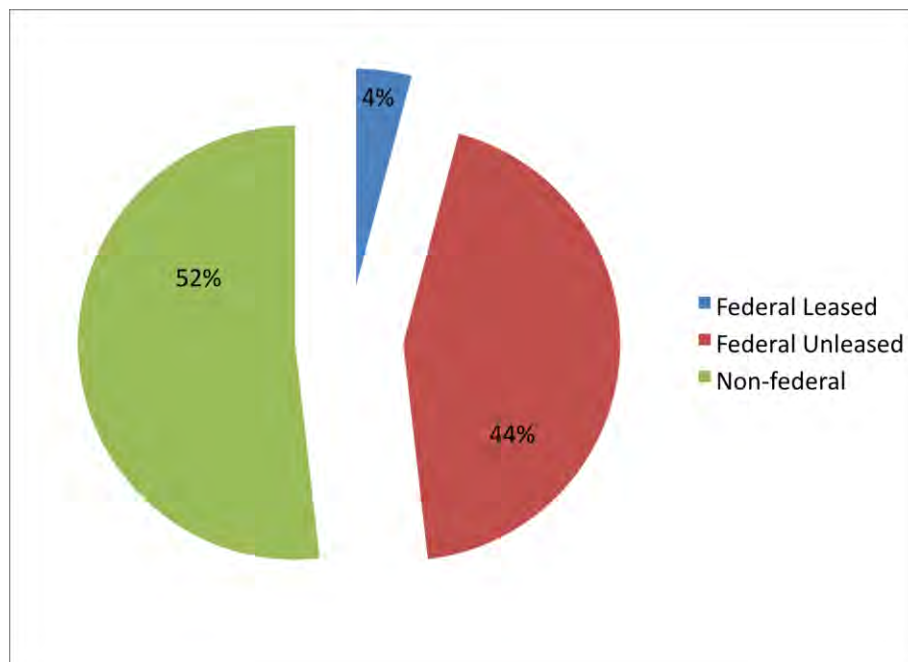


Figure 9. Relative potential emissions of federal and non-federal fossil fuels

Leased and unleased federal fossil fuels

Unleased and leased federal fossil fuels were examined to measure the GHG pollution from past leasing and to estimate the potential GHG emissions of unleased federal fossil fuels. Leased emissions are calculated using volumes of proved offshore and onshore oil and gas, volumes of offshore and onshore oil and gas underlying non-producing leased land, amounts of leased coal, and volumes of leased oil shale. The potential GHG emissions from unleased fossil fuel resources are approximately ten times greater than the emissions from currently leased federal fossil fuels.

Table 3. GHG Emissions (Gt CO₂e) from leased and unleased federal fossil fuels

	Low	Median	High
Federal Leased (Total)	29.96	34.65	42.69
<i>Crude Oil</i>	6.95	7.38	7.92
<i>Natural Gas</i>	10.39	11.01	12.88
<i>Coal</i>	10.68	14.19	19.66
<i>Oil Shale</i>	1.94	2.07	2.23
Federal Unleased (Total)	319.00	369.98	449.53
<i>Crude Oil</i>	37.03	39.32	42.19
<i>Natural Gas</i>	37.86	40.13	47.26

<i>Coal</i>	115.32	153.19	212.26
<i>Oil Shale</i>	123.17	131.67	142.07
<i>Tar Sands</i>	5.62	5.67	5.75

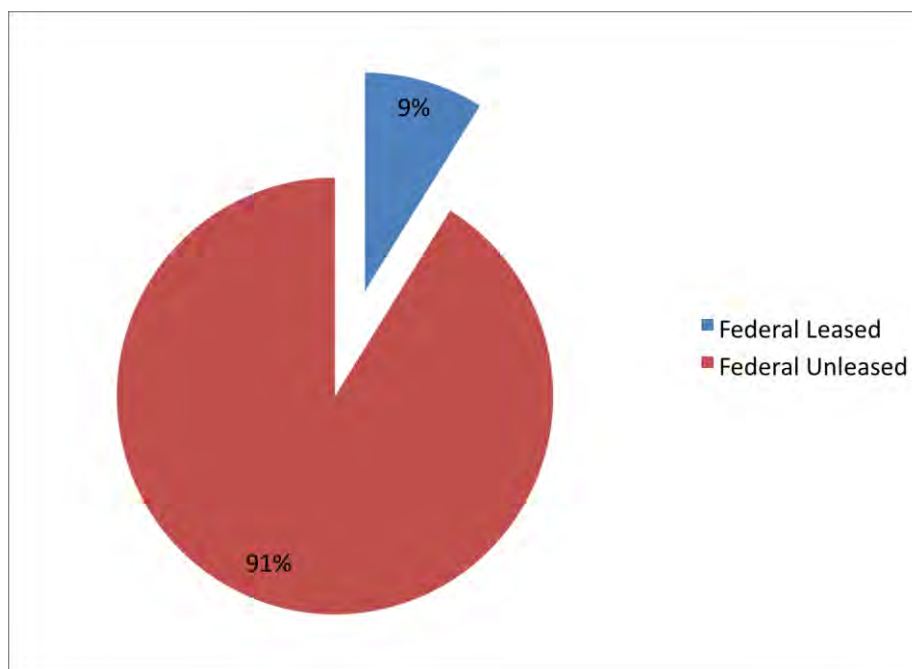


Figure 10. Low GHG emission factor scenario for leased and unleased federal fossil fuels

Unleased federal fossil fuels by resource type

The GHG emissions from unleased federal fossil fuels were evaluated by resource type. In a low emissions factor scenario, coal and oil shale are the biggest contributors of greenhouse gases. Under a high emissions factor scenario, coal is the biggest contributor of GHG pollution.

Table 4. GHG emissions (GtCO₂e) from unleased federal fossil fuels by resource type

	Low	Median	High
Federal Unleased			
<i>Crude Oil</i>	37.03	39.32	42.19
<i>Natural Gas</i>	37.86	40.13	47.26
<i>Coal</i>	115.32	153.19	212.26
<i>Oil Shale</i>	123.17	131.67	142.07
<i>Tar Sands</i>	5.62	5.67	5.75

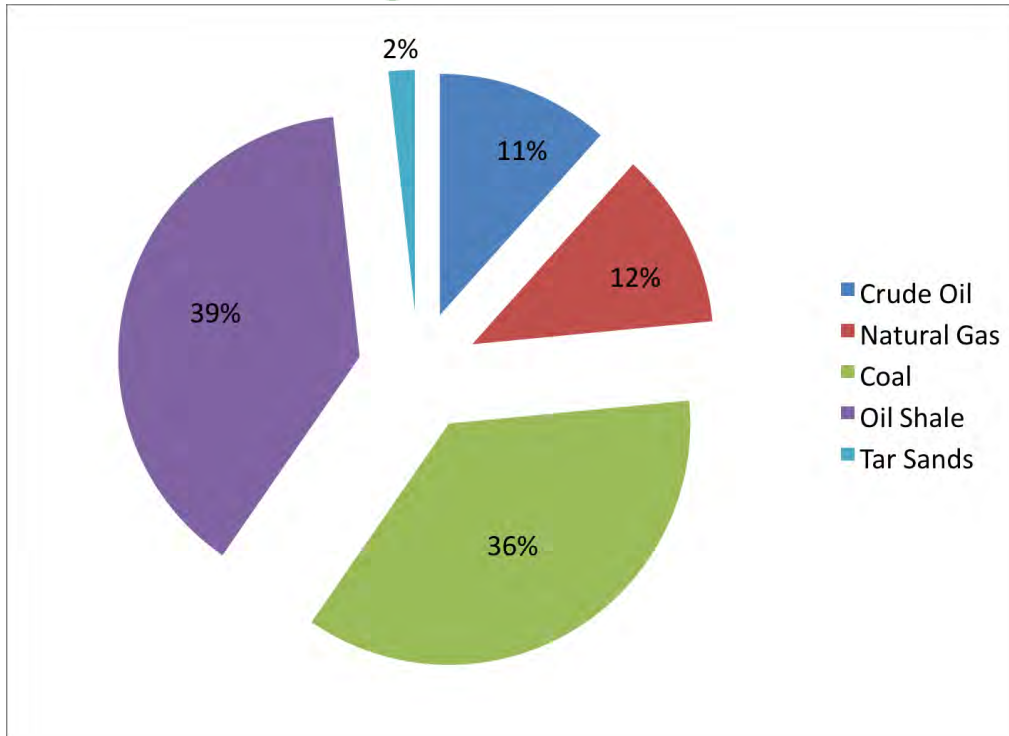


Figure 11. GHG emissions from unleased federal fossil fuels by resource type (low emissions scenario)

Coal

The potential greenhouse gas emissions from unleased recoverable coal reserves and leased recoverable coal reserves range from 115 to 212 Gt. This analysis used “recoverable coal reserves” when estimating the GHG emissions from coal, which is a common and conservative estimate of the portion of coal that could be extracted.

Table 5. GHG emissions (GtCO₂e) from federal coal

	Mass (MMST)	Low	Median	High
Federal Recoverable Coal Reserves				
<i>Unleased</i>	86,204	115.32	153.19	212.26
<i>Leased</i>	7,376	10.68	14.19	19.66

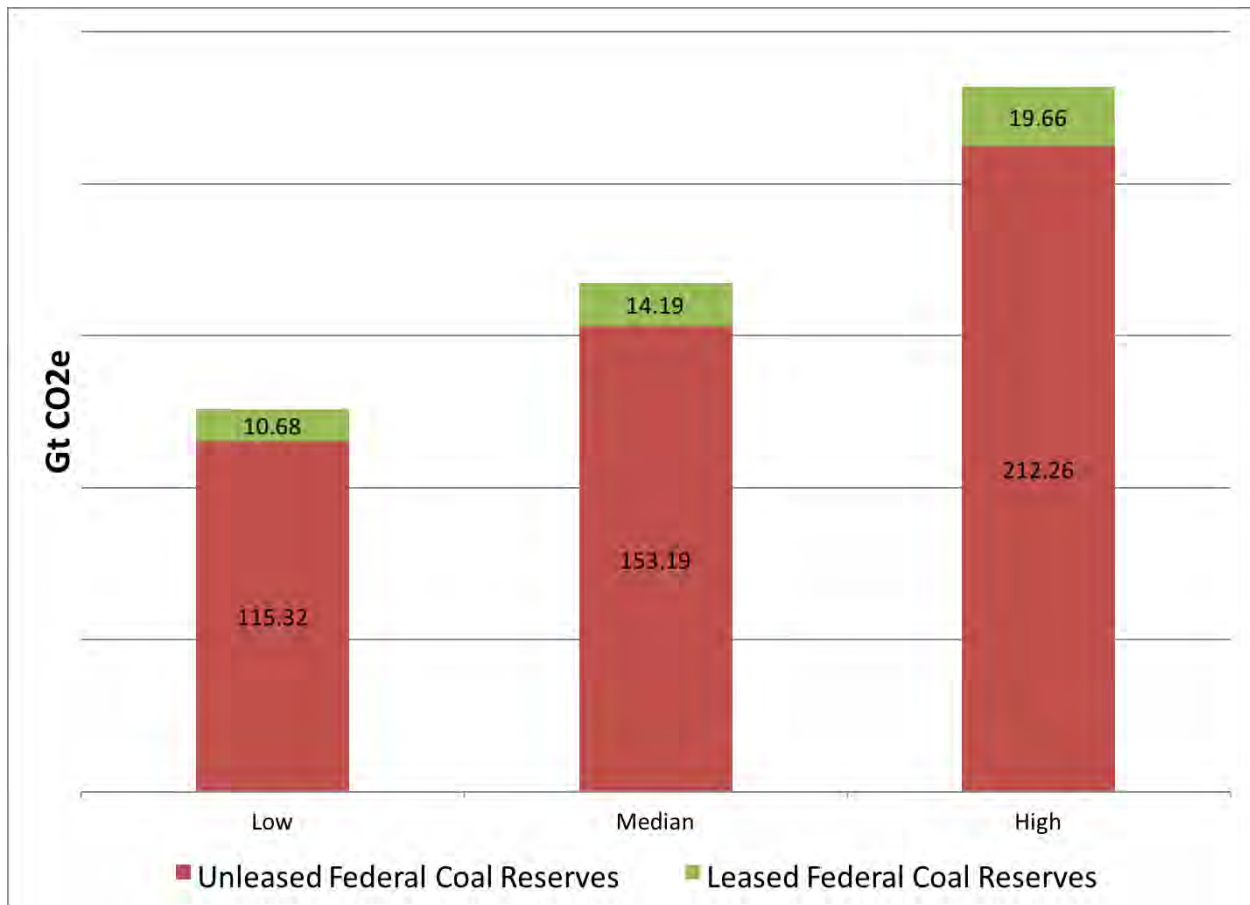


Figure 12. GHG emissions from federal coal under low, median and high emissions scenarios

Oil Shale

We analyzed the potential GHG emissions of federal oil shale and the portion of federal oil shale that is available for leasing under current federal policies. Since the life cycle GHG emissions of oil shale extraction and production are more than 50% greater than conventional crude oil per unit energy, oil shale resource results in the most potential GHG emissions per unit of energy delivered for all fossil fuels except coal. Federal oil shale includes only the resource that is geologically prospective according to deposit grade and thickness criteria in the Bureau of Land Management’s (BLM) 2012 Final Oil Shale and Tar Sands Programmatic EIS and Record of Decision. Geologically prospective oil shale resources in Colorado and Utah are deposits that yield 25 gallons of shale oil per ton of rock (gal/ton) or more and are 25 feet thick or greater. In Wyoming geologically prospective resources are deposits that yield 15 gal/ton or more and are 15 feet thick or greater. Our analysis assumes that geologically prospective federal oil shale resources that are not currently available for leasing can potentially become available for leasing in the future because they are under federal mineral rights.

Table 6. GHG emissions (GtCO₂e) from federal geologically prospective oil shale

	Volume (MMBbls)	Low	Median	High
Federal Oil Shale				
<i>Available for Lease Under PEIS and ROD & RD&D Leases</i>	75,606	24.65	26.35	28.44
<i>Total in Place Resource</i>	383,678	123.17	131.67	142.07

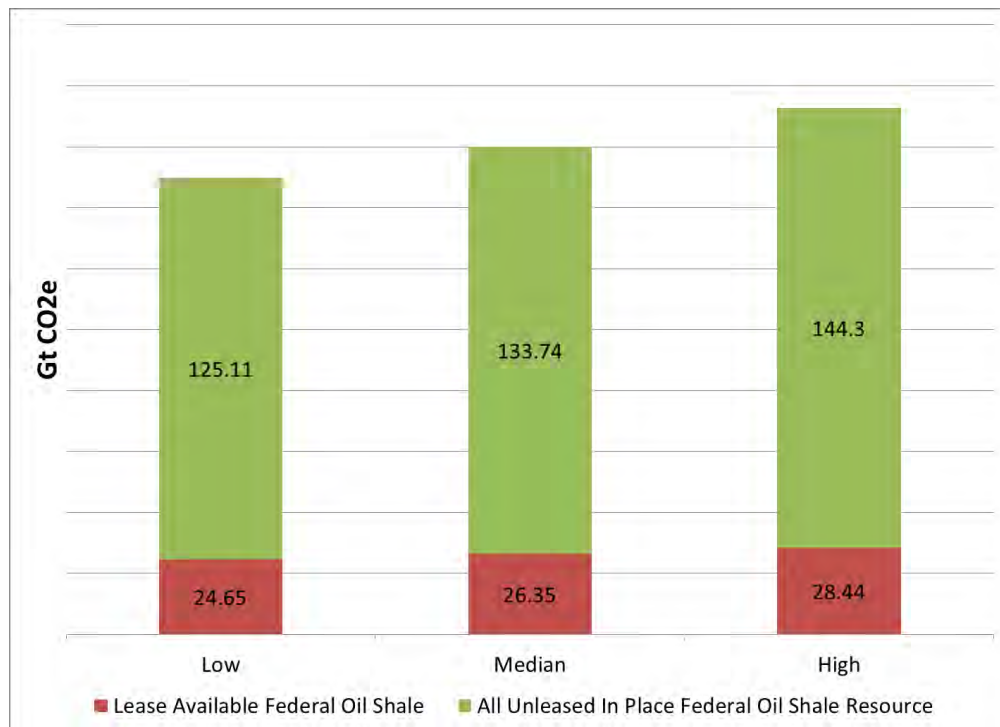


Figure 13. GHG emissions (Gt CO₂e) from federal oil shale under low, median and high emissions scenarios

Crude Oil

The potential GHG emissions of onshore and offshore federal crude oil range from 9.38 to 10.69 and 27.65 to 31.50 Gt CO₂e respectively. The potential GHG emissions of all federal crude oil range from 37.03 to 42.19 Gt CO₂e.

Table 7. GHG emissions (GtCO₂e) from federal crude oil

	Volume (MMBbls)	Low	Median	High
Unleased Federal Crude Oil				
<i>Onshore</i>	33,648	9.38	9.96	10.69
<i>Offshore</i>	74,649	27.65	29.36	31.50
<i>Total</i>	120,433	37.03	39.32	42.19

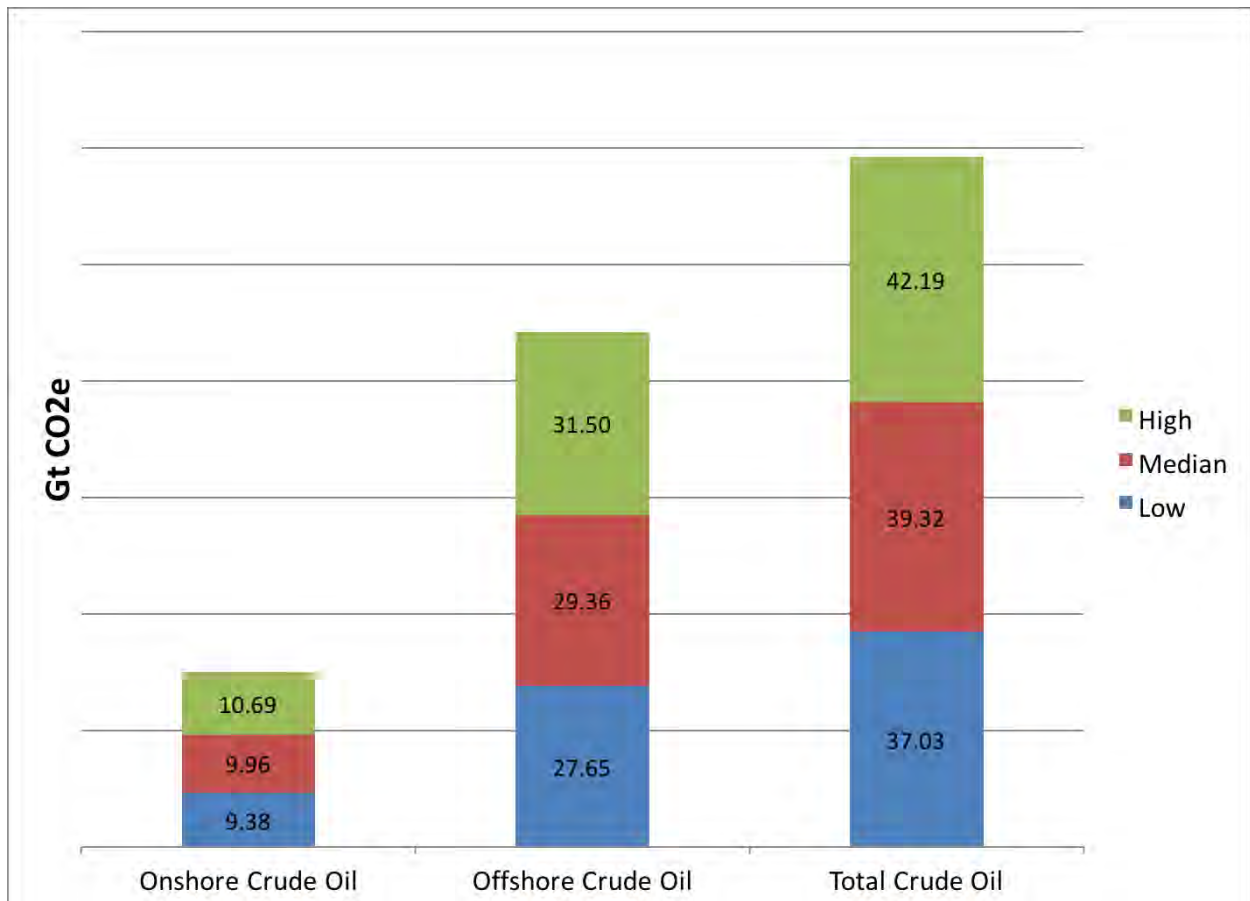


Figure 14. GHG emissions (GtCO₂e) from unleased federal crude oil

Natural Gas

Natural gas emissions were found to be 8–9% of total potential GHG emissions from federal fossil fuels.

Table 8. GHG emissions (GtCO₂e) from federal natural gas

	Volume (Tcfg)	Low	Median	High
Unleased Federal Natural Gas				
<i>Onshore</i>	231	13.79	14.61	17.21
<i>Offshore</i>	405	24.07	25.52	30.05
<i>Total</i>	635	37.86	40.13	47.26

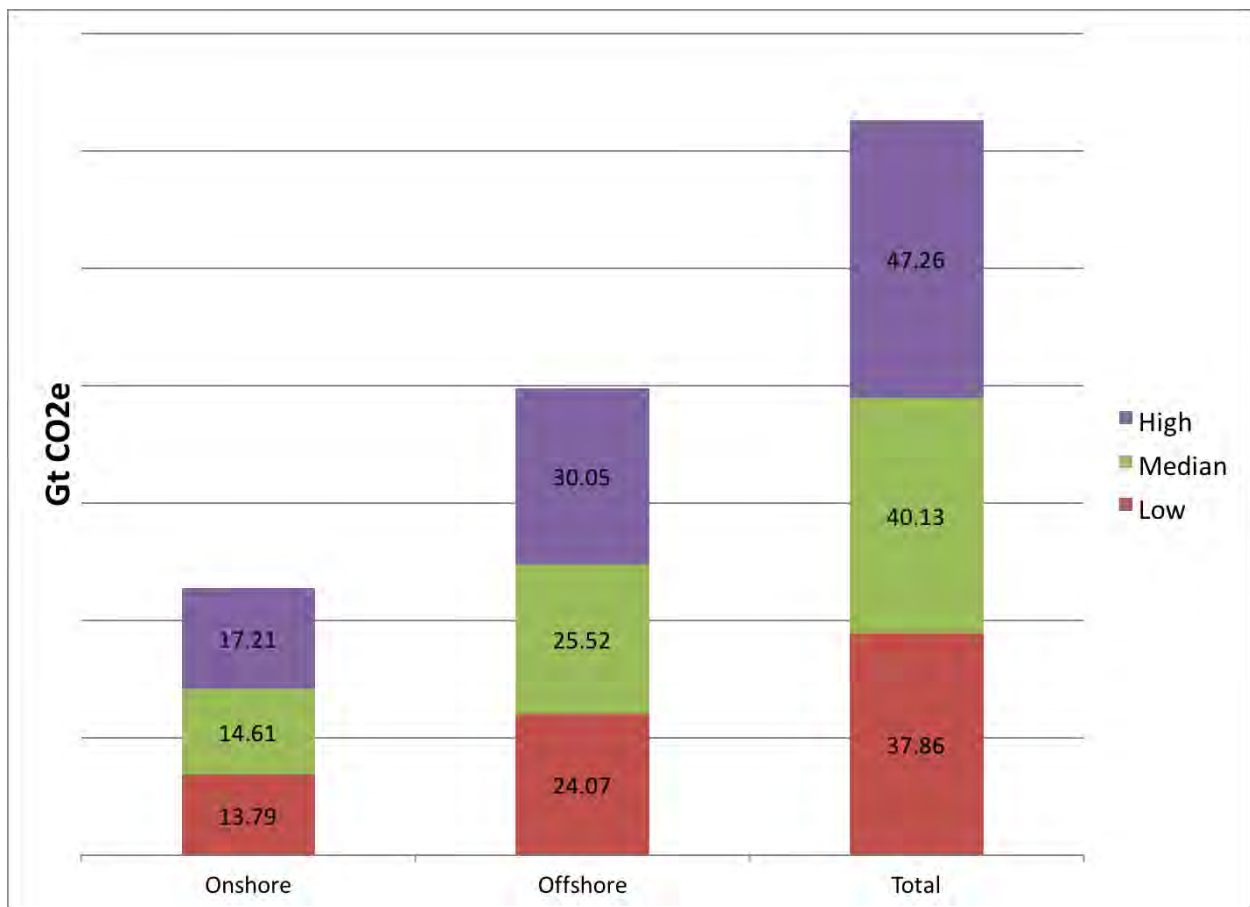


Figure 15. GHG emissions (GtCO₂e) from unleased federal natural gas

Tar Sands

Federal tar sands account for 1-2% of total potential GHG emissions from federal fossil fuels. However, it should be noted that the emissions per barrel of oil processed from tar₂₅

sands is significantly greater than that of crude oil per unit energy. Processing more tar sands into gasoline increases the GHG intensity of that fuel.

Table 9. GHG emissions (GtCO₂e) from federal tar sands

	Volume (MMBbls)	Low	Median	High
Federal Tar Sands				
<i>Lease Available</i>	4,125	1.40	1.41	1.43
<i>Total In Place Resource</i>	16,551	5.62	5.67	5.75

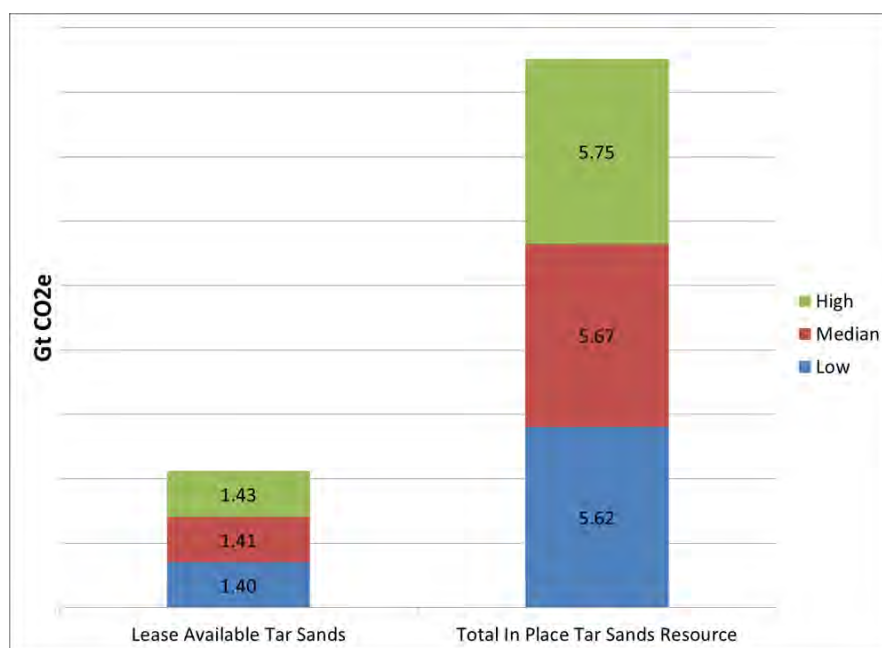


Figure 16. GHG emissions (GtCO₂e) from federal tar sands

IV. Conclusion

This report is the first to estimate the GHG emissions associated with developing federal and non-federal fossil fuels in the United States. Our results show the 100-year global warming potential of emissions resulting from the potential extraction, processing and combustion of fossil fuels under federal mineral rights. The potential GHG emissions savings associated with all federal fossil fuels, leased and unleased, is 349 to 492 GtCO₂e. Our results indicate that a cessation to new federal fossil fuel leasing could keep up to 450 Gt CO₂e from the global pool of potential future GHG emissions.

Studies that have apportioned global emissions quotas among the world's countries indicate that the U.S. share of the global emissions is limited, with varying estimates depending on the equity principles used. For example, Raupach et al. (2014) estimated three U.S. GHG emissions quota scenarios of 85 Gt CO₂e, 220 Gt CO₂e, and 356 Gt CO₂e necessary to maintain only a 50 percent likelihood of avoiding 2°C (3.6°F)

warming by century's end, depending on the equity assumptions used within a total global emissions limit. These represent a range of approximate equity assumptions for apportioning emissions quotas. Under any of those quotas, emissions from new federal fossil fuel leasing are precluded given the potential emissions from already-leased federal fossil fuels and those of non-federal fossil fuels.

Appendix I: Methodology

A1. Quantity of fossil fuels on federal lands

Determining the available fossil fuel volumes on federal lands is the starting point for analyzing the potential GHG emissions (see Appendix II: Table 1). Our approach classified fossil fuels into five broad categories: crude oil, natural gas, coal, oil shale and tar sands. We reviewed the resources used in prior research and determined that the most reliable sources for volumes of fossil fuels on federal lands are the agencies that manage them such as the Bureau of Land Management (BLM), Energy Information Agency (EIA), US Geological Survey (USGS), Office of Natural Resource Revenue (ONRR) and the Department of Interior (DOI).

Where possible we have used the volumes of fossil fuels on federal lands as they are presented in our sources. Where no volume was available, we had to estimate volumes. Onshore and offshore crude oil and natural gas under lease do not have volume estimates available. Data from the Office of Natural Resource Revenue (ONRR) on fiscal years 2014 lease volume revenue and acreage were used, alongside other fossil fuel resource data, to estimate volumes of crude oil and natural gas under lease. Oil shale available under Bureau of Land Management research, development and demonstration (RD&D) leases and its oil shale and tar sands programmatic environmental impact statement and record of decision (OSTS PEIS and ROD) do not have associated volume estimates. Volume estimates were constructed for:

- Onshore Crude Oil Under Lease
- Offshore Crude Oil Under Lease
- Onshore Natural Gas Under Lease
- Offshore Natural Gas Under Lease
- Coal Under Lease
- Oil Shale Available for Lease Under PEIS and ROD
- Oil Shale Available Under RD&D Leases
- Total In Place Federal Oil Shale Resources
- Tar Sands: In Place Federally Owned Resources
- Tar Sands: Lease Available Special Tar Sands Areas
- Unleased Federal Crude Oil
- Unleased Federal Natural Gas
- Unleased Federal Coal

- Unleased Federal Oil Shale
- Unleased Federal Tar Sands
- Non-federal fossil fuels

Onshore Crude Oil Under Lease

The 2008 EPCA inventory estimates the amount of crude oil and natural gas. We used 2014 data to estimate what portion is under active lease. To calculate onshore crude oil under lease, we use the following equation:

$$OCO_{UL} = [ONG_{AUL} \times (FLA_{TRO} \div TA_{AFL})] + OCO_{PR}$$

Where:

OCO_{UL} = Onshore Crude Oil Under Lease, in MMBls

ONG_{AUL} = Fiscal Year 2014 Oil & Natural Gas Nonproducing Acres Under Active Lease

FLA_{TRO}

= Federal lease Available Technically Recoverable Onshore Oil

TA_{AFL} = Total Acres Available for Lease from Figure ES3 of EPCA Phase 3 Inventory 2008

OCO_{PR} = Onshore Crude Oil, Proved, from EPCA Phase 3 Inventory 2008

Offshore Crude Oil Under Lease

To calculate offshore crude oil under lease, we use the following equation:

$$OFCO_{UL} = [OFA_{UAL} \times (OFCO_{LGM} \div OFCO_{LGM A})] + OFCO_{PR}$$

Where:

$OFCO_{UL}$ = Offshore Crude Oil Under Lease, in MMBbbls

OFA_{UAL} = 2015 Offshore Nonproducing Acres Under Active Lease

$OFCO_{LGM}$ = Offshore Crude Oil Leased in Gulf of Mexico Nonproducing Volume

$OFCO_{LGM A}$ = Offshore Crude Oil Nonproducing Acres Leased in Gulf of Mexico

$OFCO_{PR}$ = Offshore Crude Oil, Proved, from EPCA Phase 3 Inventory 2008

Onshore Natural Gas Under Lease

To calculate onshore natural gas under lease, we use the following equation:

$$ONG_{UL} = [ONG_{AUL} \times (FLA_{TRNG} \div TA_{AFL})] + ONG_{PR}$$

Where:

ONG_{UL} = Onshore Natural Gas Under Lease, in Tcfg

ONG_{AUL} = Fiscal Year 2014 Oil and Natural Gas Nonproducing Acres Under Lease

FLA_{TRNG} = Federal Lease Available Technically Recoverable Onshore Natural Gas

TA_{AFL} = Total Acres Available for Lease from Figure ES3 of Phase 3 Inventory 2008

ONG_{PR} = Onshore Natural Gas, Proved, from EPCA Phase 3 Inventory 2008

Offshore Natural Gas Under Lease

To calculate offshore natural gas under lease, we use the following equation:

$$OFNG_{UL} = [OFA_{UAL} \times (OFNG_{LGM} \div OFNG_{NP})] + OFNG_{PR}$$

Where:

$OFNG_{UL}$ = Offshore Natural Gas Under Lease, in Tcfg
 OFA_{UAL} = Offshore Nonproducing Acres Under Active Lease
 $OFNG_{LGM}$ = Offshore Natural Gas Leased in Gulf Of Mexico Nonproducing Volume
 $OFNG_{NP}$ = Offshore Natural Gas Nonproducing Acres Leased in Gulf of Mexico
 $OFNG_{PR}$ = Offshore Natural Gas, Proved, from EPCA Phase 3 Inventory

Coal Under Lease

Since nominal amounts of coal under lease were not available, we had to estimate them based on data from GAO, BLM, and the percentage of leased and unmined coal reserves remaining in the Powder River Basin. To calculate coal under lease, we used the following equation:

$$C_L = \sum RLC [(LFC_{A,1990-2012} \div LFC_{T,1990-2012}) \times LFC_{A,2013}] \times RFC_R$$

Where:

C_L = Coal Under Lease, in MST
 $\sum RLC$ = Sum of Remaining Leased Coal for each of the following States (AL, CO, KY, MT, NM, ND, OK, UT, WY, Eastern States)
 $LFC_{A,1990-2012}$ = Leased Federal Coal in Acres (for each state) for the period 1990 – 2012, from Table 1 in GAO 2013
 $LFC_{T,1990-2012}$ = Leased Federal Coal in Tons (for each state) for the period 1990 – 2012, from Table 1 in GAO 2013
 $LFC_{A,2013}$ = Total Leased Federal Coal Acres in Effect (for each state) in 2013 from BLM 2014
 RFC_R = Percentage of leased and unmined coal reserves remaining in Powder River Basin (40.4%) from Wright 2015

Oil Shale Available for Lease Under PEIS and ROD

To calculate the volume of oil shale available for lease under both the PEIS and ROD, we separately estimate the available resource in Utah, Colorado and Wyoming, and sum these estimates.

To estimate the available resource for lease in UT, we use the following equation:

$$OSR_{UT} = AAROD_{UT} \times AR_{UT}$$

Where:

OSR_{UT} = Oil Shale Resource for lease in Utah, in MMBbls
 $AAROD_{UT}$ = Available Area in Utah According to Record of Decision
 AR_{UT} = Average Resource in Utah's Uintah Basin, in bbl/acre

To estimate the available resource for lease in CO, we use the following equation:

$$OSR_{CO} = AAROD_{CO} \times AR_{CO}$$

Where:

OSR_{CO} = Oil Shale Resource in Colorado, in MMBbls
 $AAROD_{CO}$ = Available Area in Colorado According to Record of Decision
 AR_{CO} = Average Resource in Colorado's Piceance Basin, in bbl/acre

To estimate the available resource for lease in WY, we use the following equation:

$$OSR_{WY} = AAROD_{WY} \times AR_{WY}$$

Where:

OSR_{WY} = Oil Shale Resource in Wyoming, in MMBbls
 $AAROD_{WY}$ = Available Area in Wyoming According to Record of Decision
 AR_{WY} = Average Resource in Wyoming's Green River and Washakie Basins, comprised of the average of 6 members, in bbl/acre

Oil Shale Available Under RD&D Leases

To calculate the volume of oil shale available under RD&D leases, we summed up the estimated volumes for the 9 leases detailed in the *Assessment of Plans and Progress on US Bureau of Land Management Oil Shale RD&D Leases in the United States*.¹⁴ Since volume estimates for the American Shale Oil LLC and AuraSource leases are not available in the document, we estimate them using the following equations:

$$OSR_{ASO} = AAL_{ASO} \times AR_{CO}$$

Where:

OSR_{ASO} = Oil Shale Resource in the American Shale Oil, LLC Lease, in MMBbls
 AAL_{ASO}
= Area Available For Lease (including preference right area) for the American Shale Oil, LLC lease
 AR_{CO} = Average Resource in Colorado's Piceance Basin, in bbl/acre

$$OSR_{AS} = AAL_{AS} \times AR_{UT}$$

Where:

OSR_{AS} = Oil Shale Resource in the AuraSource Lease, in MMBbls
 AAL_{AS} = Area Available For Lease (including preference right area) for the AuraSource lease
 AR_{UT} = Average Resource in Utah's Uintah Basin, in bbl/acre

Total In Place and Geologically Prospective Federal Oil Shale Resources

To calculate the total in place federal oil shale resources, we summed the federal resource available in the Piceance Basin with a yield of over 25 GPT (gallon per ton) in USGS 2010, the federal resource available in the Green River and Washakie Basins of over 15 GPT in USGS 2011, and separately estimated the federal resource available in the Uintah basin.

To estimate the federal resource in the Uintah basin, we use the following equation

$$FOSR_{UB} = AAROD_{UT} \times AR_{UT}$$

Where:

$FOSR_{UB}$ = Federal Oil Shale Resource in the Uintah Basin, in MMBbls
 $AAROD_{UT}$ = Available Area in Utah According to Record of Decision
 AR_{UT} = Average Resource in Uintah Basin, in bbl/acre

Tar Sands: In Place Federally Owned Resources

To calculate the volume of in place federally owned tar sands resources, we use the following equation:

$$TS_{FOR} = \sum SRfp$$

Where:

TS_{FOR} = In Place Federally Owned Tar Sands Resources, in MMBbl
 $\sum SRfp$ = the sum of the federally owned percentages of tar sands resource for each state

As mentioned above, we sum the federally owned percentages of tar sands resources as listed in *Natural Bitumen Resources of the United States*.¹⁵ Where no federal ownership percentage is given in the document, we cite research by Keiter et al. 2012 for the percentage of Utah tar sands that are federal and Gorte et al. 2011 for all other states.

Tar Sands: Lease Available STSAs

To calculate the volume for Lease Available STSAs, we multiply the area available for each STSA by the resource for that area. STSA areas are taken from as presented in the 2013 ROD.¹⁶

The available resource for each area is taken from *Unconventional Energy Resources: 2013 Review*.¹⁷ This review unfortunately does not provide estimates for Raven Ridge

or San Rafael STSAs; for those, we used a low per-acre estimate (from the P.R. Spring STSA) of 25,900 barrels per acre. We then sum all of these volumes.

Unleased Federal Crude Oil

To calculate unleased federal offshore crude oil, we use the following equation:

$$OFCO_{ULL} = OFCO_{TR}$$

Where:

$OFCO_{ULL}$ = Unleased Federal Offshore Crude Oil

$OFCO_{TR}$ = Technically Recoverable Federal Offshore Crude Oil

To calculate unleased federal onshore crude oil, we use the following equation:

$$OCO_{ULL} = OCO_{TR}$$

Where:

OCO_{ULL} = Unleased Federal Onshore Crude Oil

OCO_{TR} = Technically Recoverable Federal Onshore Crude Oil

Unleased Federal Natural Gas

To calculate unleased federal offshore natural gas, we use the following equation:

$$OFNG_{ULL} = OFNG_{TR}$$

Where:

$OFNG_{ULL}$ = Unleased Federal Offshore Natural Gas

$OFNG_{TR}$ = Technically Recoverable Federal Offshore Natural Gas

To calculate unleased federal onshore natural gas, we use the following equation:

$$ONG_{ULL} = ONG_{TR}$$

Where:

ONG_{ULL} = Unleased Federal Onshore Natural Gas

ONG_{TR} = Technically Recoverable Federal Onshore Natural Gas

Unleased Federal Coal

To calculate unleased federal coal, we use the following equation:

$$FC_{ULL} = FC_{RR} - \left\{ \left(\frac{FC_{TIR}}{BLM_{AUM}} \right) \times CLA_{2013} \right\}$$

Where:

FC_{ULL} = Unleased Federal Coal

FC_{RR} = Federal Recoverable Coal Reserves from NMA 2012

FC_{TIR} = Total Federal In Place Coal Resource from USDA, USDOE, USDOJ 2007

BLM_{AUM} = Acres Under BLM Management from BLM 2014

CLA_{2013} = 2013 Leased Coal Acres from BLM 2014

Unleased Federal Oil Shale

To calculate unleased federal oil shale, we subtract Federal Oil Shale Available under RD&D Leases from DOE/BLM 2013 from Total In Place Geologically Prospective Federal Oil Shale Resources as described earlier.

Unleased Federal Tar Sands

To calculate unleased federal tar sands, we assume the total in place federal tar sands resources are unleased.

Non-federal Fossil Fuels

Non-federal fossil fuels volumes are calculated for each fossil fuel category by subtracting federal fossil fuel volumes from total technically recoverable oil resources, total technically recoverable natural gas resources, and total us recoverable coal reserves in the U.S. as provided by EIA 2012a. There are no non-federal tar sands and oil shale resources studied in this study.

For each oil, natural gas and coal resource:

$$NFFF = TTR - FFF$$

Where:

$NFFF$ = Non-federal Fossil Fuel

TTR = Total Technically Recoverable Resource

FFF = Federal Fossil Fuel

A2. Fossil Fuel to Primary Energy Conversions

We converted volumes of fossil fuels into primary energy as this allowed us to make necessary adjustments and apply resource specific life-cycle GHG emissions factors, as those are presented in units of energy. For example, the life-cycle GHG emissions factors are typically on a product-delivered basis (kWh of electricity, MJ of thermal energy), so the fossil fuel reserves must be adjusted because only a portion of the fossil fuel becomes a final product delivered.

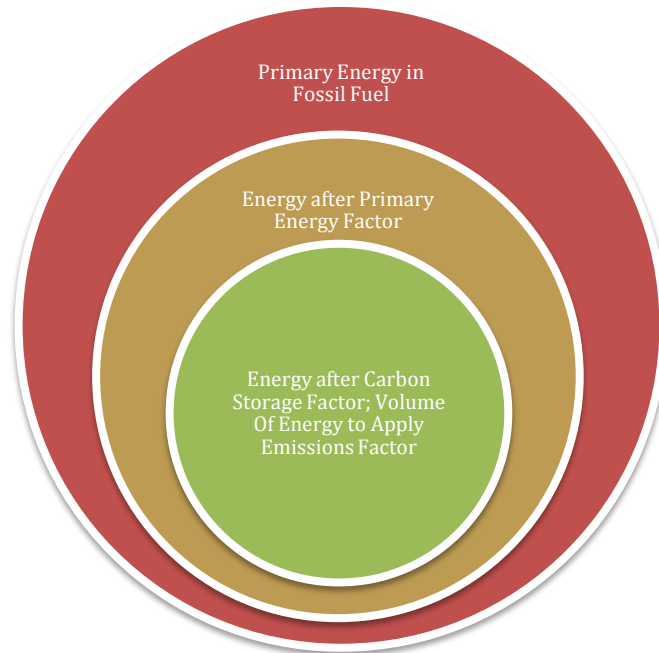


Figure A17. Determining quantities of energy to multiply by emissions factor

We used the following assumptions to convert fossil fuel amounts to primary energy:

Table A10. Energy content of fossil fuels

Fossil Fuel	Energy Content	Source
Crude Oil	5,746 MJ / barrel (LHV)	ORNL 2011
Natural Gas	983 btu / ft3 (LHV)	ORNL 2011
Coal	20.61 btu / ton (HHV)	ORNL 2011
Oil Shale	5,746 MJ / barrel (LHV)	ORNL 2011
Tar Sands	5,746 MJ / barrel (LHV)	ORNL 2011

Proportions of Resource Used as Input for End-use Products

The proportions of resource used as input for end-use products were needed in order to appropriately divide the initial fossil fuel amounts. The proportions make it possible to apply end-use product specific life-cycle emissions factors, which account for the full

life-cycle GHG emissions associated with each end-use product. These proportions do not take into account the energy required to process the fossil fuel resource and move it downstream. They only describe a percentage of the fossil fuel resource that will ultimately be used in end-use products and sectors.

Crude Oil

Proportions of Crude Oil used for various end-use products were derived from the EIA.¹⁸ To calculate proportions each of the top seven petroleum products consumed in 2013 was divided by the total annual consumption of petroleum products. These top seven products are:

- Finished Motor Gasoline
- Distillate Fuel Oil
- Kerosene
- Liquefied Petroleum Gases (LPG)
- Petroleum Coke
- Still Gas
- Residual Fuel Oil

Dividing the consumption of each end product by the total annual consumption of petroleum products enabled us to reconstruct the demand for petroleum products, and thus the hypothetical product output of a crude oil refinery.

For this method, we used the following equation:

$$CO_{EUPP} = AC_{EUP} \div AC_{APP}$$

Where:

CO_{EUPP} = Crude Oil End Use Product Proportion
 AC_{EUP} = Annual Consumption of End Use Product
 AC_{APP} = Annual Consumption of All Petroleum Products

Natural Gas

Proportions of Natural Gas used for each end-use sector were derived from the EIA's *Natural Gas Consumption by Sector in the Reference case, 1990-2040: History: U.S. Energy Information Administration, Monthly Energy Review*.¹⁹ For each end-use sector, the sector specific annual natural gas consumption was divided by the total annual natural gas consumption. These end-use sectors are:

- Residential
- Commercial
- Industrial
- Electric Power
- Transportation

For this method we used the following equation:

$$NG_{EUSP} = AC_{EUS} \div AC_{ANG}$$

Where:

NG_{EUSP} = Natural Gas End Use Sector Proportion

AC_{EUS} = Annual Consumption by End Use Sector

AC_{ANG} = Annual Consumption of All Natural Gas

Coal

Proportions of Coal used for each end-use sector were derived from the EIA's *Quarterly Coal Report – April – June 2014: Table 32 - U.S. Coal Consumption by End-Use Sector, 2008 – 2014*.²⁰ For each end-use sector, the sector specific annual coal consumption was divided by the total annual coal consumption. These end-use sectors are:

- Electric Power
- Coke
- Other Industrial Use

For this method, we use the following equation:

$$C_{EUSP} = AC_{EUS} \div AC_{AC}$$

Where:

C_{EUSP} = Coal End Use Sector Proportion

AC_{EUS} = Annual Consumption by End Use Sector

AC_{AC} = Annual Consumption of All Coal

Oil Shale

For oil shale we assume the same end-use products will be refined from a barrel of crude oil derived from oil shale. We apply the same end-use product proportions as calculated for Crude Oil.

Tar Sands

For tar sands we assume the same end-use products will be refined from a barrel of crude oil derived from tar sands as has been assumed in other research.²¹ We apply the same end-use product proportions as calculated for Crude Oil.

Primary Energy Factors

Making energy products requires energy. To account for the energy in the reserve required to make the final end products, we determined a ratio of primary energy to the end use, resulting in a Primary Energy Factor. The Primary Energy Factor represents the relationship between the amount of energy required to make the end product and the amount of end product. In the case of coal-based electricity, it is the amount of energy needed to make 1 kWh of coal fired electricity, which will always be >1 kWh. For this study only about 30% of the total coal resource becomes electricity delivered from coal-fired generation; it requires about 3.3 kWh of coal resource to make and deliver 1 kWh of coal electricity. Our methodology assumes the energy required to process the fossil fuel resource into the end product is internal, meaning it comes from the resource. This means that some portion of the fossil fuel resource is consumed making the fossil fuel product. The primary energy factor helps understand the total amount of fossil fuel products and has no impact on the life-cycle GHG emissions, which are accounted for in the emissions factors.

For many end products, primary energy factors are available, as “source energy factors” from the National Renewable Energy Laboratory’s *Fuels and Energy Precombustion LCI Data Module*.²² We used these source energy factors, which represent the energy required to extract, process, and deliver fuel, as Primary Energy Factors. We used NREL’s ‘source energy factors’ for all end products except:

- Natural Gas Use in the Electric Power Sector
- Coal Use in the Electric Power Sector
- Coal Use in manufacturing Metallurgical Coke
- Coal Use in Other Industrial Use
- End Products Derived from Oil Shale and Tar Sands

Natural Gas Use in the Electric Power Sector

To calculate the Primary Energy Factor for Natural Gas Use in the Electric Power Sector, we converted the volume (ft³) of Natural Gas delivered in 2013 to customers in the Electric Power Sector from EIA’s *February 2015 Monthly Energy Review*²³ into kWh, took the 2013 net electrical generation from Natural Gas (kWh) by Electric Power Sector customers in EIA’s *February 2015 Monthly Energy Review*,²⁴ and the source energy factor for Natural Gas from Deru and Torcellini 2007.

To calculate the Primary Energy Factor for Natural Gas Use in the Electric Power Sector, we used the following equation:

$$PEFNG_{EPS} = NGD_{EPS} \div NEGNG_{EPS}$$

Where:

$PEFNG_{EPS}$ = Primary Energy Factor for Natural Gas Use in the Electric Power Sector

NGD_{EPS} = Natural Gas Delivered to Electric Power Sector Customers in 2013

$NEGNG_{EPS}$ = Net Electrical Generation from Natural Gas by Electric Power

For other Natural Gas end-use sectors, we assume all heat not converted to electricity is useful. For the Electric Power Sector, however, we assume all heat is lost.

Coal Use in the Electric Power Sector

For Coal Use in the Electric Power Sector, we converted the quantity of coal consumed by the Electric Power Sector in *Quarterly Coal Report – April – June 2014: Table 32 - U.S. Coal Consumption by End-Use Sector, 2008 – 2014*²⁵ into kWh, we took the 2013 net electrical generation from Coal (kWh) by Electric Power Sector customers in EIA’s *February 2015 Monthly Energy Review (2015b)*, and the source energy factor for Coal.²⁶

To calculate the Primary Energy for Coal Use in the Electric Power Sector, we used the following equation:

$$PEFC_{EPS} = CD_{EPS} \div NEGC_{EPS}$$

Where:

$PEFC_{EPS}$ = Primary Energy Factor for Coal Use in the Electric Power Sector

CD_{EPS} = Coal Delivered to Electric Power Sector Customers in 2013

$NEGC_{EPS}$ = Net Electrical Generation from Coal by Electric Power Customers in 2013

For Coal Use in the manufacture of Metallurgical Coke, we used values in World Coal Association 2015. For Coal Use in Other Industrial Use, we use the same Primary Energy Factor as that calculated for Coal Use in the Electric Power sector.

End Products Derived From Oil Shale and Tar Sands

The primary energy resource available for end products derived from oil shale and tar sands needs to be adjusted for the increased energy required to extract and process both the oil shale and tar sands. We assume the additional energy required for these processes comes from the primary energy resource itself, otherwise referred to as ‘internal’ energy. Since the primary energy factors used²⁷ are aggregates of several components (exploration, extraction, processing, and refining into end products), and do not list the primary energy factors for each of these components, we had to disaggregate the factors and backwards calculate the primary energy factor of just the refining component. To do this we use the following equation for each end product derived from crude oil:

$$PEFCO_{REP} = (PEFCO_{EP}) - \left(\frac{1}{EROI_{CO}}\right)$$

Where:

$PEFCO_{REP}$

= Primary Energy Factor of Refining the End Product From Crude Oil, exclusive of energy required for exploration, extraction, and processing

$PEFCO_{EP}$ = Primary Energy Factor of End Product, inclusive of all processes

$EROI_{CO}$ = Energy Return On Investment from Crude Oil

For End Products Derived from Oil Shale, we adjust the Primary Energy Factors of refining components of end products derived from Crude Oil by the following adjustment mechanism:

$$PEFOS_{EP} = PEFCO_{REP} + \left(\frac{1}{EROI_{OS}} \right)$$

Where:

$PEFOS_{EP}$ = Primary Energy Factor of Oil Shale Derived End Product

$PEFCO_{REP}$ = Primary Energy Factor of Refining Component of End Product

$EROI_{OS}$ = Energy Return ON Investment from Oil Shale, from Brand 2009

For End Products Derived from Tar Sands, we adjust the Primary Energy Factors of refining components of end products derived from Crude Oil by the following adjustment mechanism:

$$PEFTS_{EP} = PEFCO_{REP} + \left(\frac{1}{EROI_{TS}} \right)$$

Where:

$PEFOS_{EP}$ = Primary Energy Factor of Oil Shale Derived End Product

$PEFCO_{REP}$ = Primary Energy Factor of Refining Component of End Product

$EROI_{OS}$ = Energy Return ON Investment from Oil Shale²⁸

Emissions Factors

The approach used in this study was to use emissions factors that represent the functional units for which we had data on fossil fuels amounts. For example, if the functional unit of the emissions factor was a kWh worth of electricity, we estimated the total amount of resource that can be converted into this functional unit. Where the emissions factor is provided on an energy unit basis that is not equivalent to that of the fossil fuel resource, we make the appropriate conversion.

All life-cycle emissions factors used in this study, and nearly all in the literature, are on an end-use product basis (i.e., kWh of electricity, MJ of final fuel combusted, km-travelled, etc.). To account for the energy in the feedstock required to make the end-use products, we determined a ratio of primary energy to the end-use product, as described 40

earlier in this Appendix. This represents the relationship between the amount of energy required to make the final product.

We were able to find resource-specific life-cycle emissions factors for all fossil fuel categories. These life-cycle emissions factors account for the greenhouse gas emissions associated with all life-cycle stages associated with the production of an end product derived from a fossil fuel feedstock.

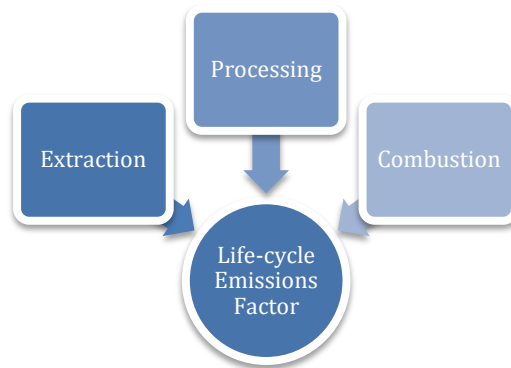


Figure A18. Example life-cycle stages accounted for in a life-cycle emissions factor

For each emissions factor we evaluated low, median and high emission factor scenarios. The base case in this study is the low emissions factor scenario, which is the most conservative estimate of the GHG emissions from developing fossil fuels. This was done to account for a static emissions factor; we optimistically assume that GHG emissions per unit energy improve over time compared to *ex post* emissions factors in the literature as more efficient energy and public policy and best practices limit fugitive emissions.

Where possible we used harmonized life-cycle emissions factors found in the literature. Harmonization is a meta-analytical process used to develop robust, analytically consistent and current comparisons of estimates of life-cycle GHG emissions factors, which have been scientifically studied and published in academic, peer-reviewed literature.

For some end-use products, however, specific emissions factors were not available in the literature. We make adjustments to the emissions factors for the following:

- Natural Gas extracted from non-conventional, shale based natural gas resource
- All end products (except Gasoline) derived from Oil Shale
- LPG, Petroleum Coke, Still Gas, and Residual Fuel Oil derived from Tar Sands
- Natural Gas Used in the Transportation Sector

Natural Gas Extracted From Non-Conventional, Shale-based Natural Gas Resource

To account for the difference in emissions resulting from conventional natural gas extraction and non-conventional natural gas extraction, we apply shale-gas specific emissions-factors to a percentage of the total Natural Gas fossil fuel volume. We assume this to be 27% and take this figure from EIA's *Technically Recoverable Shale Oil and Shale Gas Resources: An Assessment of 137 Shale Formations in 41 Countries Outside the United States* (2013). We use shale-gas specific emissions factors from Burnham et al. 2012 and Heath et al. 2014.

All End Products (Except Gasoline) Derived From Oil Shale

Specific emissions factors for finished motor gasoline derived from oil shale was available in the literature. Emissions factors for the remainder of the end products, however, were not.

To account for the difference in emissions between conventional crude oil extraction and processing and the extraction and processing of Oil Shale into an equivalent barrel of standard crude oil, we adjust the end product specific emissions factors using the following equation:

$$OSE_{AF} = (FMG_{OS} - FMG_{CO}) \div FMG_{CO}$$

Where:

OSE_{AF} = Oil Shale Emissions Adjustment Factor

FMG_{OS} = Finished Motor Gasoline from Oil Shale Emissions Factor from Brandt 2009

FMG_{CO} = Finished Motor Gasoline from Crude Oil Emissions Factor from Burnham, et al. 2012

We then multiply each crude oil end product specific emissions factor by $(1 + OSE_{AF})$ to appropriately increase the emissions factor due to the increased emissions resulting from Oil Shale extraction and processing. The emissions factor from Brandt 2009 used above is an Oil Shale specific emissions factor.

LPG, Petroleum Coke, Still Gas and Residual Fuel Oil Derived From Tar Sands

Specific emissions factors for finished motor gasoline, distillate fuel oil and kerosene were available in the literature. However, specific emissions factors for other end-use products were not. To account for the difference in emissions between conventional crude oil extraction and processing and the extraction and processing of Tar Sands into an equivalent barrel of standard crude oil, we adjust the end product specific emissions factors using the following equation:

TSE_{AF} = the average of:

$$(FMG_{TS} - FMG_{CO}) \div FMG_{CO};$$

$$(DFO_{TS} - DFO_{CO}) \div DFO_{CO};$$

and

$$(K_{TS} - K_{CO}) \div K_{CO}$$

Where:

TSE_{AF} = Tar Sands Emissions Adjustment Factor

FMG_{TS} = Finished Motor Gasoline from Tar Sands Emissions Factor²⁹

FMG_{CO} = Finished Motor Gasoline from Crude Oil Emissions Factor³⁰

DFO_{TS} = Distillate Fuel Oil from Tar Sands Emissions Factor³¹

DFO_{CO} = Distillate Fuel Oil from Crude Oil Emissions Factor³²

K_{TS} = Kerosene from Tar Sands Emissions Factor³³

K_{CO} = Kerosene from Crude Oil Emissions Factor³⁴

We then multiply the LPG, Petroleum Coke, Still Gas and Residual Fuel Oil from Crude Oil emissions factors by $(1 + TSE_{AF})$.

Natural Gas Used in the Transportation Sector

In order to more accurately estimate the emissions from natural gas use in the transportation sector, we use EIA data³⁵ to determine what percentage of natural gas is used by light duty compressed natural gas (CNG) vehicles, and what percentage is used by medium and heavy duty CNG vehicles. We then apply these proportions to the transportation portion of natural gas primary energy volumes.

To calculate GHG emissions, we use life-cycle emissions factors for CNG transportation.³⁶ Since the emissions factors from Burnham et al. are measured in km-travelled, we need the fuel economy to determine the distance each mode of transport can travel based upon a unit of gas. We use EPA data to estimate the fuel economy of light duty vehicles.³⁷ For the fuel economy of medium and heavy duty vehicles, we cite research from NREL.³⁸ Once energy available is expressed in the functional units of the life-cycle emissions factors, we can estimate potential GHGs.

Research Limitations

There are several limitations to this model. The major limitation is the unavailability of some kinds of data that would allow for a better approximation of global warming potential from developing fossil fuels. For example, tar sands reserves are not well characterized as amounts are reported in “acres” and estimates must be made by applying a “barrel per acre” estimate instead of absolute amounts, which would be easier to compare with other reserves. In addition, existing fossil fuel amounts under lease were mostly unavailable. There is also no specific data for all of the crude oil end products. Literature on life-cycle emissions factors for oil shale and tar sands not as extensive as for other resources and come with higher ranges of uncertainty. There is also no federal ownership of figures for Tar Sands in Alabama, Texas, California, Kentucky, New Mexico, Wyoming and Oklahoma. Finally, emissions factors used in this study were static over time and based on *ex post* (actual) data. Our GHG emissions

model assumes that the combustion efficiency or GHG intensity across the fleet of U.S. fossil fuel-fired power plants remains static over time.

Appendix II: Data Sources

Table A11. Fossil fuel amounts and sources

Fossil Fuel Type	Quantity	Source(s) Used
Crude Oil		
Offshore		
Federal Technically Recoverable	89,930 MMBbls	BOEM 2014
Federal Proved (2013)	5,137 MMBbls	EIA 2015a
FY 2014 Crude Oil Volume Revenues Reported	396.36 MMBbls	ONRR 2014
February 2015 Producing Leases – Acreage	4,980,054 acres	BOEM 2015
Acreage Under Active Lease	32,184,001 acres	BOEM 2015
Leased in Gulf of Mexico (non-producing/not subject to exploration & development plans)	17,900 MMBbls	DOI 2012
Non-producing Acreage Leased in Gulf of Mexico	23,849,584 acres	BOEM 2015
All Non-producing Acreage Leased	27,203,947 acres	DOI 2012
Onshore		
Federal Technically Recoverable	30,503 MMBbls	EPCA Phase 3 Inventory 2008
Federal Lease Available Technically Recoverable*	18,989 MMBbls	EPCA Phase 3 Inventory 2008
Federal Proved	5,344 MMBbls	EPCA Phase 3 Inventory 2008
FY 2014 Crude Oil Volume Revenues Reported	146.23 MMBbls	ONRR 2014
FY 2014 O&NG Producing Leases – Acreage	12,690,806 acres	BLM 2014a
FY 2014 O&NG Acres Under Lease	34,592,450 acres	BLM 2014a
Total Technically Recoverable Resource	220,200 MMBbls	EIA 2012a
Natural Gas		
Offshore		
Technically Recoverable	404.52 Tcfg	BOEM 2014
Federal Proved Gas	25.33 Tcfg	EIA 2014c
FY 2014 Natural Gas Volume Revenues Reported	0.85 Tcfg	ONRR 2014
February 2015 Producing Leases – Acreage	4,980,054 acres	BOEM 2015
Acreage Under Active Lease	32,184,001 acres	BOEM 2015
Leased in Gulf of Mexico (non-producing/not subject to exploration & development plans)	49.70 Tcfg	DOI 2012
Non-producing Acreage Leased in Gulf of Mexico	23,849,584 acres	BOEM 2015
All Non-producing Acreage Leased	27,203,947 acres	BOEM 2015
Onshore		
Technically Recoverable	230.98 Tcfg	EPCA Phase 3 Inventory 2008
Lease Available Technically Recoverable*	194.907 Tcfg	EPCA Phase 3 Inventory 2008
Proved Gas	68.76 Tcfg	EPCA Phase 3 Inventory 2008

Total Technically Recoverable Resource	2,203.30 Tcfg	EIA 2012a
Coal		
In Place Federal Coal Resources	957,000 MST	USDA, DOE, DOI 2007
Federal Recoverable Coal Reserves	87,000 MST	National Mining Association 2012
Total U.S. Recoverable Reserves	256,000 MST	EIA 2012b
2013 Leased Coal Acres	474,025 acres	BLM 2014b
2013 Coal Production	422.25 MST	ONRR 2013
Oil Shale		
Available Area According to ROD – UT*	360,400 acres	BLM ROD 2013
Available Area According to ROD – CO*	26,300 acres	BLM ROD 2013
Available Area According to ROD – WY*	292,000 acres	BLM ROD 2013
Average Resource – UT	74,093 bbl/acre	BLM OSTS 2012
Average Resource – WY	120,117 bbl/acre	BLM OSTS 2012
Average Resource – CO	300,000 bbl/acre	Mercier, et al. 2010
Resource Available in Piceance Basin	284,800 MMBbls	USGS 2010
Resource Available in Green River and Washakie Basins	72,179 MMBbls	USGS 2011
Resource Available in Uinta Basin	26,699 MMBbls	BLM OSTS 2012; BLM ROD 2013
Available Under RD&D Leases	5,938 MMBbls	DOE/BLM 2013
Tar Sands		
In Place Tar Sands Resources	54,095 MMBbls	USGS 2006
Federal Ownership of Utah Tar Sands	58%	Keiter et al. 2011
Federal Ownership of Other Tar Sands	28%	Gorte et al. 2012
Lease Available STSAs*	4,125 MMBbls	BLM OSTS 2012

* “Lease-available” federal fossil fuels are unleased federal fossil fuels that are available for leasing under current federal policies and plans.

Table A12. End-use products/sectors and life-cycle emissions factor sources

End-use Product / Sector	Key Parameter(s) for Influencing Low, Median, High Emissions Scenarios	Life-Cycle Emission Factor Source(s) Used
<u>Crude Oil</u>		
Gasoline	Associated gas venting and flaring; vehicle end-use efficiency	Burnham et al. 2012
Distillate Fuel Oil	Extraction and transport	NETL 2008, 2009 as cited in US DOS 2014
Kerosene	Extraction and transport	NETL 2008, 2009 as cited in US DOS 2014
Liquefied Petroleum Gases (LPG)	Extraction and transport	Venkatesh et al. 2010
Petroleum Coke	Extraction and transport	Venkatesh et al. 2010
Still Gas	Extraction and transport	Venkatesh et al. 2010
Residual Fuel Oil	Extraction and transport	Venkatesh et al. 2010
<u>Natural Gas</u>		
Residential	Liquid unloadings (venting); well equipment (leakage and venting); transmission and distribution (leakage and venting)	Burnham et al. 2012
Commercial	Liquid unloadings (venting); well equipment (leakage and venting); transmission and distribution (leakage and venting)	Burnham et al. 2012
Industrial	Liquid unloadings (venting); well equipment (leakage and venting); transmission and distribution (leakage and venting)	Burnham et al. 2012
Electric Power	Power conversion efficiency	Heath et al. 2014
Transportation	Liquid unloadings (venting); well equipment (leakage and venting); transmission and distribution (leakage and venting)	Burnham et al. 2012
<u>Coal</u>		
Electric Power	Transmission and distribution losses; power conversion efficiency; coal mine methane	Whitaker et al. 2012
Coke		EPA 2004
Other Industrial Use	Transmission and distribution losses; power conversion efficiency; coal mine methane	Whitaker et al. 2012
<u>Oil Shale</u>		
Gasoline	Retorting; upgrading; refining	Brandt 2009
Distillate Fuel Oil	Retorting; upgrading; refining; extraction	Brandt 2009; Burnham et al. 2012; NETL 2008, 2009 as cited in US DOS 2014
Liquefied Petroleum Gases (LPG)	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham et al. 2012; Venkatesh et al. 2010
Kerosene	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham et al. 2012; NETL 2008, 2009 as cited in US DOS 2014
Petroleum Coke	Retorting; upgrading; refining;	Brandt 2009; Burnham et al. 2012;

	extraction; transport	Venkatesh et al. 2010
Still Gas	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham, et al. 2012; Venkatesh et al. 2010
Residual Fuel Oil	Retorting; upgrading; refining; extraction; transport	Brandt 2009; Burnham et al. 2012; Venkatesh et al. 2010
Tar Sands		
Gasoline	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAx 2009 as cited in DOS 2014
Distillate Fuel Oil	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, and NETL 2008, 2009 as cited in DOS 2014
Liquefied Petroleum Gases (LPG)	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAx 2009 as cited in US DOS 2014; Venkatesh et al. 2010
Kerosene	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	NETL 2008, 2009 as cited in DOS 2014
Petroleum Coke	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAx 2009 as cited in DOS 2014; Venkatesh et al. 2010
Still Gas	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAx 2009 as cited in DOS 2014; Venkatesh et al. 2010
Residual Fuel Oil	Feedstock mixture (consisting of dilbit, synthetic crude oil, bitumen)	Jacobs 2009, NETL 2008, 2009, and TIAx 2009 as cited in DOS 2014; Venkatesh et al. 2010

Table A13. Crude oil end products and emissions factors

Crude Oil End-use Product	Proportion of Resource Used as Input for End-use Product	Carbon Storage Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Finished Motor Gasoline	46.46%	0.00	86 tons CO ₂ e / TJ Fuel Combusted	92 tons CO ₂ e / TJ Fuel Combusted	98 tons CO ₂ e / TJ Fuel Combusted	1.19
Distillate Fuel Oil	17.92%	0.50	89 tons CO ₂ e / TJ Fuel Combusted	90 tons CO ₂ e / TJ Fuel Combusted	96 tons CO ₂ e / TJ Fuel Combusted	1.16
Kerosene	7.51%	0.00	86 tons CO ₂ e / TJ Fuel Combusted	88 tons CO ₂ e / TJ Fuel Combusted	91 tons CO ₂ e / TJ Fuel Combusted	1.21
Liquefied Petroleum Gases	12.75%	0.59	80 tons CO ₂ e / TJ Fuel Combusted	88 tons CO ₂ e / TJ Fuel Combusted	100 tons CO ₂ e / TJ Fuel Combusted	1.15
Petroleum Coke	1.87%	0.30	130 tons CO ₂ e / TJ Fuel Combusted	144 tons CO ₂ e / TJ Fuel Combusted	160 tons CO ₂ e / TJ Fuel Combusted	1.05
Still Gas	3.72%	0.59	78 tons CO ₂ e / TJ Fuel Combusted	87 tons CO ₂ e / TJ Fuel Combusted	100 tons CO ₂ e / TJ Fuel Combusted	1.09
Residual Fuel Oil	1.70%	0.00	88 tons CO ₂ e / TJ Fuel Combusted	95 tons CO ₂ e / TJ Fuel Combusted	110 tons CO ₂ e / TJ Fuel Combusted	1.19
Asphalt*	1.71%	1.00		--		--
Other Oils*	0.56%	1.00		--		--
Lubricants*	0.64%	1.00		--		--
Other*	5.16%	1.00		--		--

Table A14. Natural gas end-use sectors and factors

Natural Gas End-use Sector (product)	Proportion of Resource Used as Input for End-use Product	Primary Energy Yield Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Residential (CHP)	18.76%	100%	72 tons CO ₂ e / MJ of fuel combusted	76 tons CO ₂ e / MJ of fuel combusted	81 tons CO ₂ e / MJ of fuel combusted	1.092
Commercial (CHP)	12.44%	100%	72 tons CO ₂ e / MJ of fuel combusted	76 tons CO ₂ e / MJ of fuel combusted	81 tons CO ₂ e / MJ of fuel combusted	1.092
Industrial (CHP)	34.14%	100%	72 tons CO ₂ e / MJ of fuel combusted	76 tons CO ₂ e / MJ of fuel combusted	81 tons CO ₂ e / MJ of fuel combusted	1.092
Electric Power (kWh)	31.69%	43.39%	117 tons CO ₂ e / MJ of fuel combusted	125 tons CO ₂ e / MJ of fuel combusted	180 tons CO ₂ e / MJ of fuel combusted	1.092
Transportation (km-travelled)	2.98%	100%	210 grams CO ₂ e / km travelled	230 grams CO ₂ e / km travelled	250 grams CO ₂ e / km travelled	1.092

Table A15. Coal end-use sectors and factors

Coal End-use Sector (product)	Proportion of Resource Used as Input for End-use Product	Primary Energy Yield Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Electric Power (kWh)	92.78%	31.65%	203 tons CO ₂ e / TJ of fuel combusted	272 tons CO ₂ e / TJ of fuel combusted	381 tons CO ₂ e / TJ of fuel combusted	1.048
Metallurgical Coke (pig iron)	2.32%	n/a		1.35 tons of CO ₂ e / ton of pig iron produced		1.167
Other Industrial Use (kWh)	4.89%	31.65%	203 tons CO ₂ e / TJ of fuel combusted	272 tons of CO ₂ e / TJ of fuel combusted	381 tons CO ₂ e / TJ of fuel combusted	1.048

Table A16. Oil shale end-use products and factors

Oil Shale End-use Product	Proportion of Resource Used as Input for End-use Product	Carbon Storage Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Finished Motor Gasoline	46.46%	0.00	130 tons CO ₂ e / TJ Fuel Combusted	141 tons CO ₂ e / TJ Fuel Combusted	150 tons CO ₂ e / TJ Fuel Combusted	1.187
Distillate Fuel Oil	17.92%	0.50	135 tons CO ₂ e / TJ Fuel Combusted	138 tons CO ₂ e / TJ Fuel Combusted	147 tons CO ₂ e / TJ Fuel Combusted	1.158
Kerosene	7.51%	0.00	130 tons CO ₂ e / TJ Fuel Combusted	135 tons CO ₂ e / TJ Fuel Combusted	139 tons CO ₂ e / TJ Fuel Combusted	1.205
Liquefied Petroleum Gases	12.75%	0.59	121 tons CO ₂ e / TJ Fuel Combusted	135 tons CO ₂ e / TJ Fuel Combusted	153 tons CO ₂ e / TJ Fuel Combusted	1.151
Petroleum Coke	1.87%	0.30	197 tons CO ₂ e / TJ Fuel Combusted	221 tons CO ₂ e / TJ Fuel Combusted	245 tons CO ₂ e / TJ Fuel Combusted	1.048
Still Gas	3.72%	0.59	118 tons CO ₂ e / TJ Fuel Combusted	133 tons CO ₂ e / TJ Fuel Combusted	153 tons CO ₂ e / TJ Fuel Combusted	1.092
Residual Fuel Oil	1.70%	0.00	133 tons CO ₂ e / TJ Fuel Combusted	146 tons CO ₂ e / TJ Fuel Combusted	168 tons CO ₂ e / TJ Fuel Combusted	1.191
Asphalt*	1.71%	1.00		--		--
Other Oils*	0.56%	1.00		--		--
Lubricants*	0.64%	1.00		--		--
Other*	5.16%	1.00		--		--

Table A17. Tar sands end-use products and factors

Tar Sands End-use Product	Proportion of Resource Used as Input for End-use Product	Carbon Storage Factor	Low Emissions Factor	Median Emissions Factor	High Emissions Factor	Primary Energy Factor
Finished Motor Gasoline	46.46%	0.00	106 tons CO ₂ e / TJ Fuel Combusted	106 tons CO ₂ e / TJ Fuel Combusted	106 tons CO ₂ e / TJ Fuel Combusted	1.187
Distillate Fuel Oil	17.92%	0.50	105 tons CO ₂ e / TJ Fuel Combusted	105 tons CO ₂ e / TJ Fuel Combusted	105 tons CO ₂ e / TJ Fuel Combusted	1.158
Kerosene	7.51%	0.00	96 tons CO ₂ e / TJ Fuel Combusted	102 tons CO ₂ e / TJ Fuel Combusted	110 tons CO ₂ e / TJ Fuel Combusted	1.205
Liquefied Petroleum Gases	12.75%	0.59	102 tons CO ₂ e / TJ Fuel Combusted	102 tons CO ₂ e / TJ Fuel Combusted	102 tons CO ₂ e / TJ Fuel Combusted	1.151
Petroleum Coke	1.87%	0.30	156 tons CO ₂ e / TJ Fuel Combusted	167 tons CO ₂ e / TJ Fuel Combusted	176 tons CO ₂ e / TJ Fuel Combusted	1.048
Still Gas	3.72%	0.59	93 tons CO ₂ e / TJ Fuel Combusted	101 tons CO ₂ e / TJ Fuel Combusted	110 tons CO ₂ e / TJ Fuel Combusted	1.092
Residual Fuel Oil	1.70%	0.00	105 tons CO ₂ e / TJ Fuel Combusted	146 tons CO ₂ e / TJ Fuel Combusted	121 tons CO ₂ e / TJ Fuel Combusted	1.191
Asphalt*	1.71%	1.00		--		--
Other Oils*	0.56%	1.00		--		--
Lubricants*	0.64%	1.00		--		--
Other*	5.16%	1.00		--		--

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End Notes

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